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SHELTER DESIGN AND ANALYSIS

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Volume 3—Environmental Engineering for Shelters

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PREFACE

This textbook presents the engineering aspects of habitability considerations for fallout shelters. It has been distributed by the Architectural and Engineering Development Division, Technical Services Directorate, Office of Civil Defense, in the interest of providing to the engineering and architectural professions additional depth of technical coverage in the field of environmental engineering.

This volume confines itself to basic theories and techniques of environmental control considerations related to fallout shelters. It is intended for use by practicing professionals enrolled as students in formal graduate level university courses under the direction of professors well versed in the methods and technology of shelter design.

The text is not intended to be used as the source of detailed background information on nuclear physics, weapons effects, or gamma radiation shielding. Current reference materials available to the practicing professionals on these subjects are the EFFECTS OF NUCLEAR WEAPONS (ENW) and TR-20 (Vol. 1), Fallout Radiation Shielding. Familiarity with the subject matters contained therein is recommended in the use of this book.

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CHAPTER I

INTRODUCTION

The civil defense program of the United States is oriented toward the development of a nationwide system of fallout shelters. These shelters, in addition to providing at least minimum protection against radioactive fallout, must be capable of sustaining a habitable environment in which the occupants can survive.

This textbook attempts to summarize in one volume the information which is presently available concerning the problems involved in maintaining the chemical and thermal environment within tolerable limits and presents methods of approach to the solution of some of those problems. It is intended for use of practicing professional architects and engineers enrolled as students in one of the graduate level courses sponsored by the Office of Civil Defense and presented under the direction of qualified experienced instructors. Every effort has been made to present the material in a form readily understood by the practicing architect and engineer and the necessity for the use of high-level mathematics has been reduced as much as possible.

It is desirable that persons using this text have a working knowledge of nuclear physics and weapons effect but no discussion of these subjects has been included. The most comprehensive work available on these subjects is THE EFFECTS OF NUCLEAR WEAPONS (3)* which is recommended as a collateral text. A basic understanding of fallout shielding techniques would also be helpful but is not essential to an understanding of the text material. Courses in Fallout Shielding Analysis are presented at frequent intervals in most areas of the United States.

*Numbers in parentheses refer to references list at the end of the book.

CHAPTER II

PSYCHROMETRICS

In order to control the thermal environment of a fallout shelter, or any other habitable space, it is necessary to supply air in the proper amount and at the proper conditions to accomplish the desired result. Normal atmospheric air is a mixture of several gases, principally nitrogen and oxygen with traces of other gases, and water vapor. It would be well, therefore, to review some of the properties of mixtures of air and water vapor and some of the processes involving such mixtures.

The mixture of air and water vapor is referred to as "moist air." If there is no water vapor in the air it is "dry air." The water vapor in moist air is steam, usually in a superheated state, and its properties can be determined from tables of properties of steam, for the conditions of pressure and temperature which exist.

The mixture will follow, very closely, Dalton's Law of Partial Pressures, which states that the total pressure exerted by a mixture of gases is the sum of the pressures which each component would exert if it occupied alone the volume of the mixture at the temperature of the mixture. Thus, for moist air:

$$P_m = P_a + P_w \qquad \text{(Eq. 2.1)}$$

Where P_m = the total pressure of the mixture
P_a = the partial pressure of the dry air
P_w = the partial pressure of the water vapor

Strictly speaking, Dalton's Law is valid only for ideal gases. However, the partial pressure of steam in moist air is normally only a fraction of a pound per square inch. When the pressure is less than about 1 psia, the ideal gas laws yield reasonably good results for steam. For air at atmospheric pressures, the ideal gas laws will yield results which are accurate to within one percent or less.

DEW POINT

In atmospheric air the water vapor is present normally as superheated steam shown as state 1 on the temperature - entropy (Ts) diagram of Figure 2.1. At this point the pressure is P_w, the partial pressure of the vapor, and the temperature is t_1, the temperature of the moist air. If the mixture is cooled so that the pressure remains constant, the temperature will decrease until it reaches point c. At this point the vapor is saturated and the mixture is commonly referred to as "saturated air," whereas it is really only the water vapor which is saturated.

The temperature at this point is referred to as the "dew point of the air" but note that it is actually the saturation temperature of the vapor for the partial pressure, P_w. Obviously any further cooling will result in condensation of some of the water vapor.

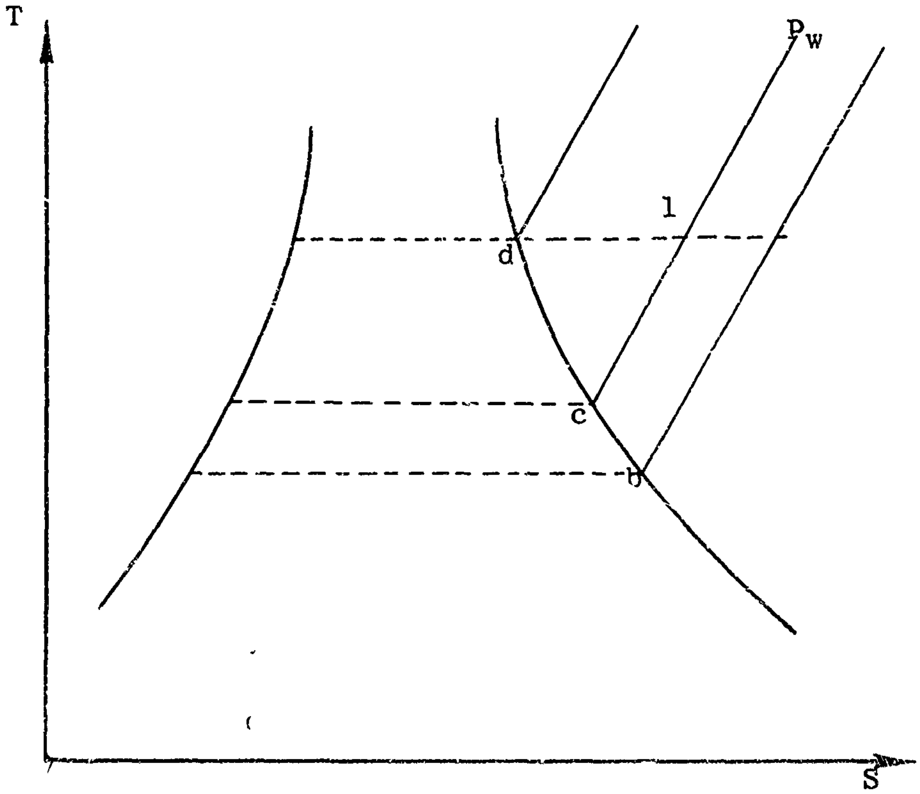

FIGURE 2.1

When some of the water vapor condenses, the remaining vapor will be saturated, but at a lower temperature, and the partial pressure will be reduced, for example to point b in Figure 2.1.

RELATIVE HUMIDITY

If the water vapor is considered to be an ideal gas, the relative humidity, ϕ, may be defined as the ratio of the partial pressure of the vapor as it exists in the mixture, P_w, to the saturation pressure of the vapor at the same temperature, P_s.

$$\phi = \frac{P_w}{P_s} \qquad \text{(Eq. 2.2)}$$

Referring again to Figure 2.1, it can be seen that the relative humidity is:

$$\phi = \frac{P_1}{P_d}$$

Still considering the water vapor to follow approximately the ideal gas laws, then:

$$PV = RT; \; P_w V_w = RT; \; P_s V_s = RT$$

$$\phi = \frac{P_w}{P_s} = \frac{RT}{V_w} \frac{V_s}{RT} = \frac{V_s}{V_w} = \frac{\rho_w}{\rho_s} \qquad \text{(Eq. 2.3)}$$

Where P = partial pressure in psfa
V = specific volume, cu ft/lb
R = specific gas constant, ft lb/lb-^{o}R
T = temperature, degrees Rankine (^{o}F + 460)
ρ = density, lb/cu ft

HUMIDITY RATIO

The humidity ratio, W, of the air-water vapor mixture is the mass of water vapor, m_w, per pound of dry-air, m_a.

$$W = \frac{m_w}{m_a} \qquad \text{(Eq. 2.4)}$$

Again applying the ideal gas relationship gives:

$$m_w = \frac{P_w V}{R_w T} \quad \frac{P_w V M_w}{\bar{R}T} \qquad m_a = \frac{P_a V}{R_a T} \quad \frac{P_a V M_a}{\bar{R}T}$$

HUMIDITY RATIO (continued)

Where:

m_w = mass of water vapor, lb
V = volume of water vapor and dry air, cu ft
R_w = specific gas constant for vapor, 85.8 ft-lb/lb-^oR
M_w = molecular weight of water vapor, 18.016 lb/mol
$\bar{R}$ = universal gas constant, 1545 ft-lb/mol-^oR
m_a = mass of dry air, lb
R_a = specific gas constant for air, 53.3 ft-lb/lb-^oR
M_a = molecular weight of air, 28.97 lb/mol

Now:

$$W = \frac{m_w}{m_a} = \frac{P_wV/R_wT}{P_aV/R_aT} = \frac{P_wR_a}{P_aR_w} = \frac{M_wP_w}{M_aP_a} = \frac{18.016}{28.97}\frac{P_w}{P_a}$$

$$W = 0.622\ \frac{P_w}{P_a} \qquad \text{(Eq. 2.5)}$$

By solving equations 2.2 and 2.5 for P_w and equating them it can be shown that:

$$\phi = \frac{WP_a}{0.622\ P_s} \qquad \text{(Eq. 2.6)}$$

EXAMPLE 2.1: 1000 cu ft of moist air are at 14.7 psia, 80^oF and 70 percent relative humidity. Calculate the humidity ratio, dew point, mass of air, and mass of vapor.

SOLUTION: From the steam tables at 80^oF

$$P_s = 0.5069 \text{ psia}$$

$$\phi = 0.70 = \frac{P_w}{P_s}$$

$$P_w = (0.70)\ (0.5069) = 0.3548 \text{ psia}$$

The dew point is the saturation temperature corresponding to this pressure. From the steam tables this is 69.4^oF. The partial pressure of the air is:

$$P_a = P - P_w = 14.70 - 0.3548 = 14.3452 \text{ psia}$$

EXAMPLE 2.1 (continued)

The humidity ratio is:

$$W = 0.622 \frac{P_w}{P_a} = 0.622 \frac{0.3548}{14.3452} = 0.0154 \frac{\text{lb vapor}}{\text{lb dry air}}$$

The mass of dry air is:

$$m_a = \frac{P_a V}{R_a T} = \frac{(14.3452)\ (144)\ (1000)}{(53.3)\ (540)} = 71.8 \text{ lb}$$

The mass of vapor can be found by the equation of state or by the humidity ratio:

$$m_w = \frac{P_a V}{R_w T} = \frac{(0.3548)\ (144)\ (1000)}{(85.7)\ (540)} = 1.105 \text{ lb}$$

$$m_w = W m_a = (0.0154)\ (71.8) = 1.105 \text{ lb}$$

DRY-BULB AND WET-BULB TEMPERATURE

The relative humidity of moist air can be determined by measuring the dry-bulb and wet-bulb temperatures. The dry-bulb temperature is the actual temperature of the air measured with a thermometer whose bulb is dry. The wet-bulb temperature is measured with a thermometer whose bulb is covered with a wet wick, usually made of cotton. If this thermometer is moved through the air, in a sling psychrometer for example, or if air is allowed to pass over it, some of the water in the wick will evaporate, assuming the air is not already saturated. The evaporation will cool the thermometer bulb causing a lower temperature reading.

The rate of evaporation depends, among other things, on the amount of moisture already in the air. If the air is saturated, none of the water in the wick will evaporate and the wet-bulb temperature will be the same as the dry-bulb temperature. The less moisture there is in the air, the greater will be the evaporation from the wick, and the more the wet-bulb temperature will be lowered. The difference between the dry-bulb and wet-bulb temperatures is the "wet-bulb depression."

The wet-bulb temperature is influenced by heat and mass

transfer rates and is therefore not the same as the "thermodynamic wet-bulb temperature," which is the temperature at which water, by evaporating into moist air, can bring the air to saturation adiabatically (without transfer of heat) at the same temperature. However they are approximately equal for air-water vapor mixtures at atmospheric pressure and temperature. This is not true for pressures and temperatures that deviate significantly from ordinary atmospheric conditions.

THE PSYCHROMETRIC CHART

With the wet-bulb and dry-bulb temperatures given, the relative humidity, humidity ratio and other properties can be determined most conveniently from a psychrometric chart, on which the properties of air-water vapor mixtures are presented in graphical form. These are available in many different forms but the one to be used here is the ASHRAE chart No. 1, developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, as shown in Figure 2.2.

This chart uses the coordinates of enthalpy and humidity ratio, with the humidity ratio lines being horizontal and enthalpy lines at an oblique angle. A dry-bulb temperature scale is shown as the abcissa; however, the dry-bulb temperature lines are not exactly parallel to each other and are inclined slightly from the vertical. The thermodynamic wet-bulb temperature lines are also oblique, almost, but not exactly, parallel to the enthalpy lines. These lines are straight but not precisely parallel to each other. Relative humidity lines are shown at intervals of 10 percent, curving from the lower left to the upper right. The saturation line is the curve for 100 percent relative humidity. Oblique lines, again not exactly parallel, are shown for volumes at intervals of 0.5 cu ft per lb of dry air. All values on the chart are on a "per lb of dry air" basis. Also shown, at the upper left, is a protractor, whose use will be explained later.

Note that the chart is applicable for a barometric pressure of 29.921 inches of mercury (14.696 psia).

The use of this chart is most conveniently explained by resolving Example 2.1, using the chart.

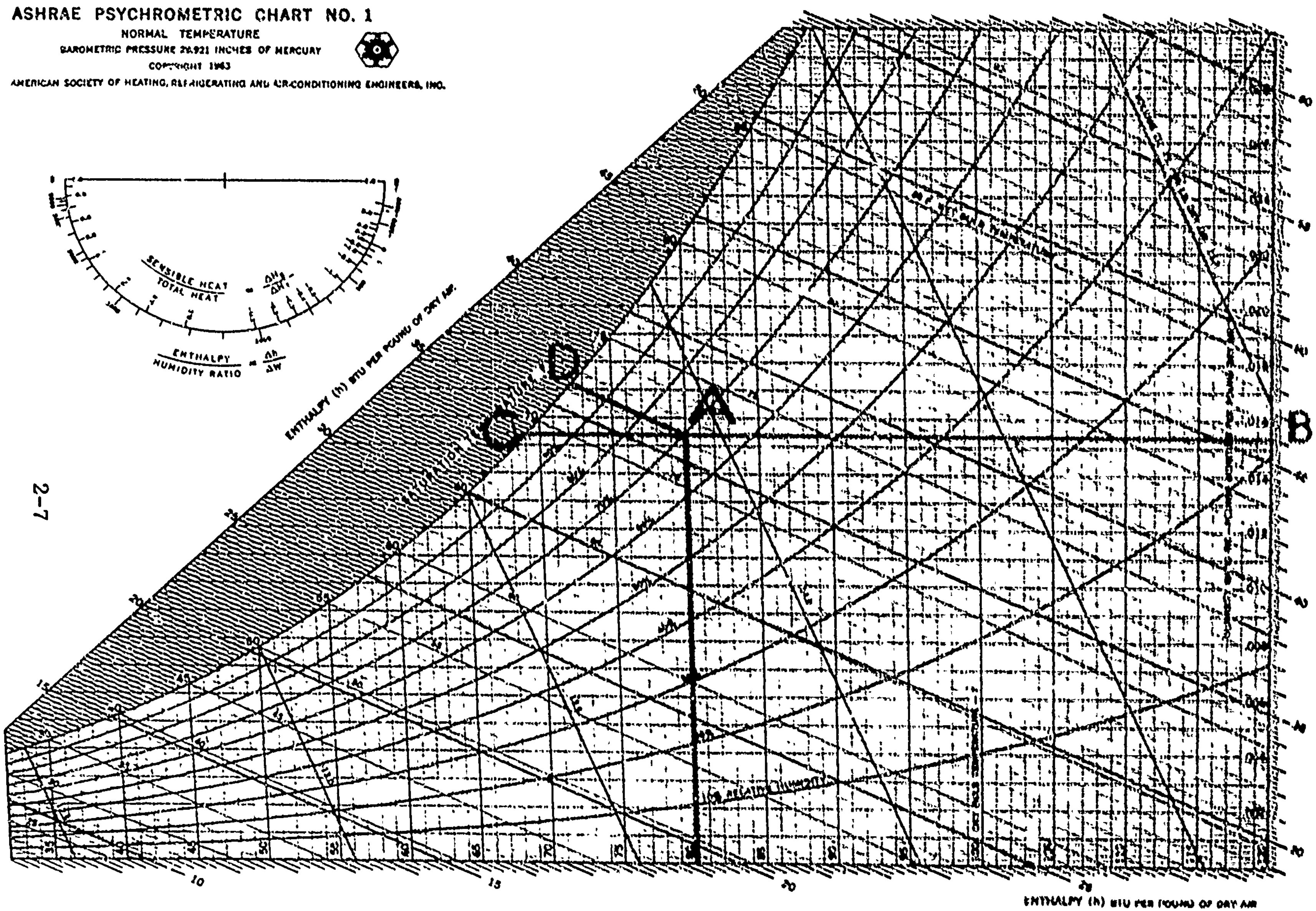

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FIGURE 2.2

SOLUTION: Locate the intersection of the 80^{o}F dry-bulb temperature line with the 70 percent relative humidity line. (Point A in Figure 2.2). From A move horizontally to the right to B and read the humidity ratio, 0.0154 lb vapor per lb dry air.

From A move horizontally to the left to read the dew point at C. It is between 69 and 70 and can be estimated at about 69.3^{o}F.

Reading obliquely from A to D will give the wet-bulb temperature of 72.5^{o}F.

The volume may be estimated at A as 13.9 cu ft per lb of dry air. The reciprocal of this is the density, 0.0719 lb/cu ft, which for 1000 cu ft gives 71.9 lb of dry air.

The mass of water vapor is determined from the humidity ratio as (0.0154) (71.9) = 1.108 lb of water vapor.

SENSIBLE HEAT AND LATENT HEAT

The sensible heat is the heat required to raise the temperature of a substance; in this case, air. Since it is assumed that enthalpy is a function of temperature only (strictly true only for an ideal gas), the change in enthalpy is the sensible heat for a given temperature change, provided that the change is accomplished at constant pressure.

Thus:

$$ {}_1Q_2 = mc_p(t_2 - t_1) \qquad \text{(Eq. 2.7)} $$

and for air:

$$ {}_1Q_2 = m_a(0.24)\ (t_2 - t_1) $$

Where:

Q = sensible heat, Btu

m = mass, lb

c_p = Specific heat at constant pressure, Btu/lb-^{o}F. For air at low temperatures the value is commonly taken as 0.24.

t = temperature, ^{o}F

The enthalpy of air at $0^{o}F$ is taken as zero. Therefore the change in enthalpy from $0^{o}F$ to t is:

$$h - h_o = c_p(t - 0)$$

$$h = c_p t = 0.24\ t \qquad \text{(Eq. 2.8)}$$

The latent heat is the heat required to change the phase of a substance. In the case of moist air it is the heat required to vaporize the water. Once the vaporization is accomplished this energy is stored in the vapor and, on condensing, the energy is given up as heat transferred to the surroundings. The latent heat changes the phase of the water but does not change the temperature, since vaporization and condensation occur at constant temperature when the pressure is constant.

Notice that the sensible heat depends on the dry-bulb temperature and the latent heat depends on the dew point temperature.

The values of enthalpy, as given on the psychrometric chart, are the enthalpy of the mixture of dry air and water vapor, per lb of dry air.

Thus:

$$h = h_a + Wh_v \qquad \text{(Eq. 2.9)}$$

Where:

h = enthalpy of the mixture, Btu/lb of dry air

h_a = enthalpy of the dry air, Btu/lb dry air

h_v = enthalpy of the vapor, Btu/lb vapor

The value of h_a can be determined from Equation 2.8. The value of h_v can be determined from:

$$h_v = 0.444\ t + 1061 \qquad \text{(Eq. 2.10)}$$

where t is the dry-bulb temperature

HEATING MOIST AIR

During the process of adding heat to moist air the humidity ratio does not change so the process can be represented by a horizontal line on the psychrometric chart. The heat which must be added is:

$$_1Q_2 = m_a(h_2 - h_1) \qquad \text{(Eq. 2.11)}$$

EXAMPLE 2.2: Heat is added to moist air at 60°F and 55% relative humidity until the temperature is 90°F. Determine the rate at which heat must be added for a flow rate of 2000 cfm.

SOLUTION: The process is shown on the skeleton psychrometric chart of Figure 2.3. From the chart at state 1 read the enthalpy of 21.1 Btu/lb dry air. Moving horizontally to the right, locate the final state at 90°F and the same humidity ratio of 0.006 lb vapor/lb dry air. At this point read the enthalpy, 28.4 Btu/lb dry air.

From the chart the volume is estimated at 13.45 cu ft/lb dry air. The mass rate of flow is:

$$m = \frac{2000 \text{ cu ft/min}}{13.45 \text{ cu ft/lb dry air}} = 149 \text{ lb dry air/min}$$

$$\text{Then:} \quad Q = 149(28.4 - 21.1) = 1088 \text{ Btu/min}$$

Note that, during this process, the relative humidity decreased from 55% to 20% although there has been no change in the humidity ratio.

COOLING MOIST AIR

The process of cooling moist air is exactly the reverse of heating, provided the air is not cooled below its original dew point. If, however, it is cooled below the dew point, some of the vapor will condense and the humidity ratio will change. Obviously the partial pressure of the vapor will decrease as will the dew point. The vapor which does not condense will be saturated at the new dew point temperature.

An energy balance for this process would be:

$$m_a h_1 = m_a h_2 + {_1Q_2} + m_w h_{w2} \qquad \text{(Eq. 2.12)}$$

COOLING MOIST AIR (continued)

Where:

m_a = mass of dry air, lb

h_1 = initial enthalpy of the mixture, Btu/lb dry air

h_2 = final enthalpy of the mixture, Btu/lb dry air

${}_1Q_2$ = heat transferred during the process

m_w = water vapor condensed to liquid, $m_a(W_1 - W_2)$, lb water

h_{w2} = Enthalpy of the saturated liquid water in equilibrium with saturated air at atmospheric pressure, Btu/lb water

Note that h_{w2} is not the enthalpy of a saturated liquid from the steam tables, since the pressure is atmospheric pressure rather than saturation pressure. It is approximately the enthalpy of a sub-cooled liquid at atmospheric pressure and the temperature of the liquid. Values can be obtained from Table 1, Chapter 21, 1967 ASHRAE Guide and Data Book, or can be approximated from:

$$h_w = h + \frac{v(P_{atm} - P)}{J}$$

Where h = enthalpy of saturated water at the temperature of the liquid, Btu/lb

v = specific volume of saturated liquid at temperature of the liquid, cu ft/lb

p = pressure of saturated liquid at the temperature of the liquid, psfa

P_{atm} = atmospheric pressure psfa

J = 778 ft-lb/Btu

Rearranging Equation 2.12 gives:

$${}_1Q_2 = m_a(h_1 - h_2) - m_w h_{w2}$$

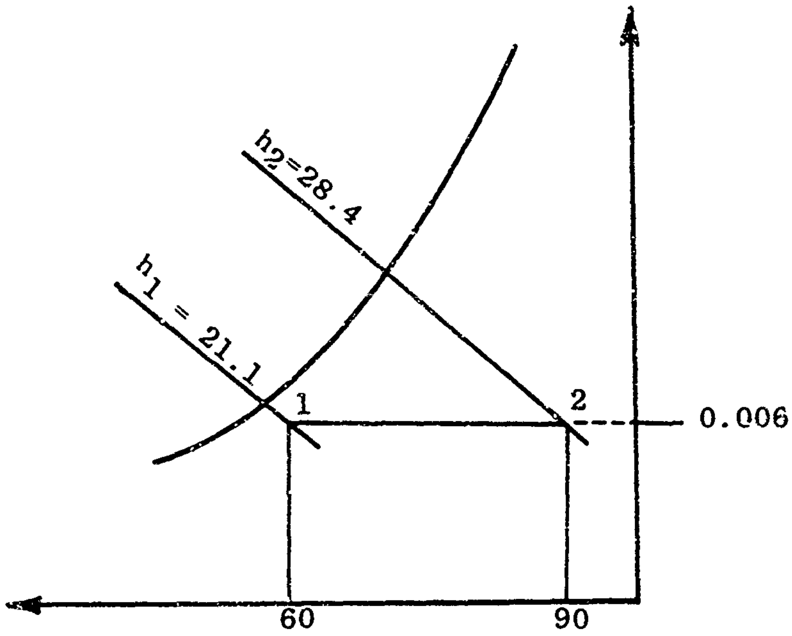

FIGURE 2.3

HEATING MOIST AIR

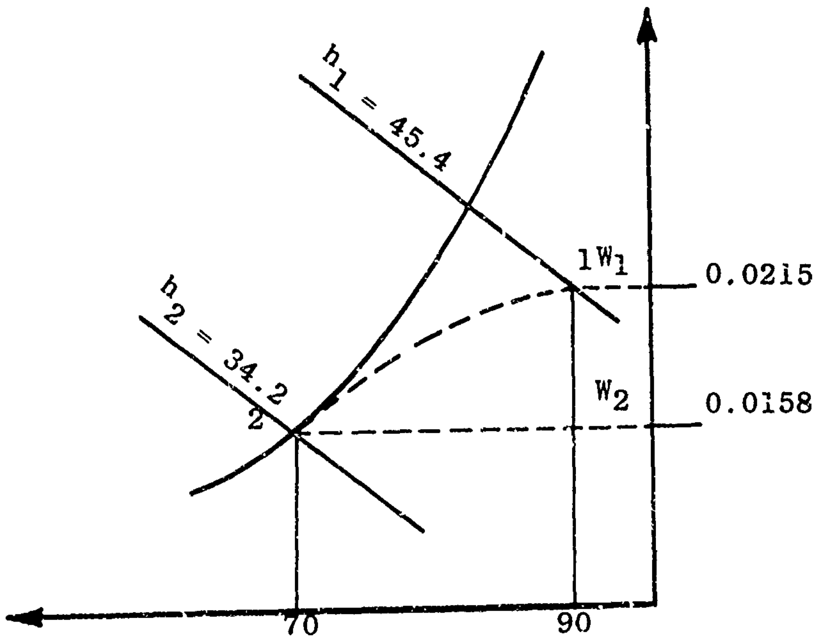

FIGURE 2.4

COOLING MOIST AIR

COOLING MOIST AIR (continued)

$$ {}_1Q_2 = m_a(h_1 - h_2) - m_a(W_1 - W_2)\,h_{w2} $$

$$ {}_1Q_2 = m_a\left[(h_1 - h_2) - (W_1 - W_2)\,h_{w2}\right] \qquad \text{(Eq. 2.13)} $$

EXAMPLE 2.3: Moist air at 90°F and 70% relative humidity is cooled at the rate of 5,000 cfm to a final temperature of 70°F. Find the heat which must be removed.

SOLUTION: The approximate process is shown on the skeleton psychrometric chart of Figure 2.4. From the chart, Figure 2.2, at condition 1, $h_1 = 45.4$ Btu/lb dry air, $W_1 = 0.0215$ lb vapor/lb dry air, and the volume is slightly over 14.3 cu ft/lb (calculation from RT/P_a yields 14.32 cu ft/lb).

The dew point is 79°F so the final temperature is below the initial dew point and Equation 2.13 would apply.

From the chart at condition 2, $h_2 = 34.2$ Btu/lb of dry air and $W_2 = 0.0158$ lb vapor/lb dry air. From Table 1, Chapter 3, 1963 ASHRAE Guide, $h_{w2} = 38.11$ Btu/lb water.

The mass flow rate of dry air is:

$$ m_a = \frac{5000}{14.3} = 350 \text{ lb/min} $$

The heat removed is:

$$ {}_1Q_2 = 350\left[(45.5 - 34.2) - (0.0215 - 0.0158)\,38.11\right] $$

$$ = 4020 \text{ Btu/min} $$

ADIABATIC MIXING OF TWO STREAMS OF MOIST AIR

In ventilation and air conditioning it is often required to mix two streams of moist air. If the mixing is adiabatic the following energy balance will hold true:

$$ m_1h_1 + m_2h_2 = m_3h_3 = (m_1 + m_2)h_3 \qquad \text{(Eq. 2.14)} $$

Where:

$$m_3 = m_1 + m_2$$

Also:

$$m_1 W_1 + m_2 W_2 = m_3 W_3 = (m_1 + m_2) W_3 \qquad \text{(Eq. 2.15)}$$

Rearranging gives:

$$\frac{h_2 - h_3}{h_3 - h_1} = \frac{W_2 - W_3}{W_3 - W_1} = \frac{m_1}{m_2} \qquad \text{(Eq. 2.16)}$$

This indicates that the state point of the mixture of the two streams lies on a straight line connecting the two state points of the streams being mixed and divides the lines into two parts which are in the same ratio as the masses of dry air in the two streams.

<u>EXAMPLE 2.4</u>: 500 cfm of moist air at 70°F and 45% relative humidity are mixed adiabatically with 2000 cfm of moist air at 90°F and 80% relative humidity. Determine the condition of the resulting mixture.

<u>SOLUTION</u>: The process is sketched on the skeleton chart in Figure 2.5. From the chart in Figure 2.2 read point 1:

$$h_1 = 48.8; \quad W_1 = 0.0247; \quad V_1 = 14.4$$

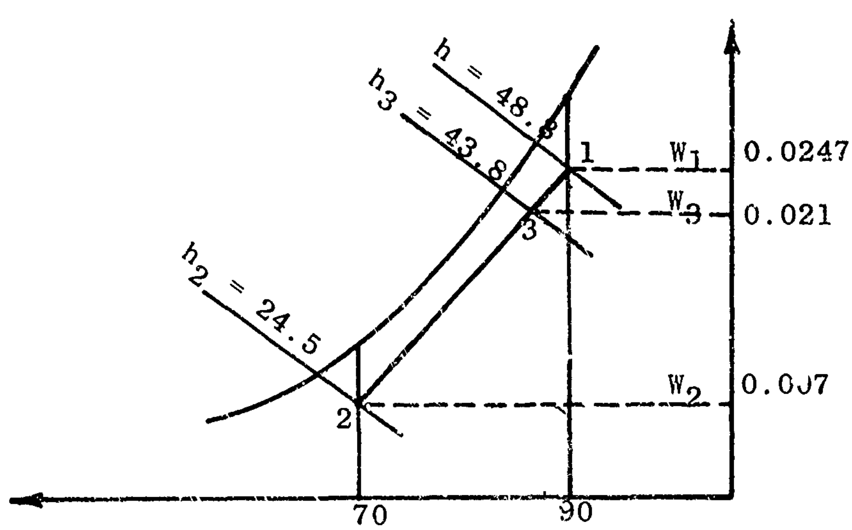

FIGURE 2.5
ADIABATIC MIXING OF TWO STREAMS OF MOIST AIR

FIGURE 2.5 (continued)

and at point 2:

$$h_2 = 24.5; \quad W_2 = 0.007; \quad V_2 - 13.5$$

Then:

$$m_1 = \frac{2000}{14.4} = 138.8 \text{ lb dry air}$$

$$m_2 = \frac{500}{13.5} = 37 \text{ lb dry air}$$

$$m_3 = m_1 + m_2 = 175.8 \text{ lb dry air}$$

The mixture point is:

$$\frac{m_1}{m_3} = \frac{138.8}{175.8} = 0.79$$

or 79% of the distance from 2 to 1. From the psychrometric chart, after scaling off this distance, the condition of the mixture of the two streams is 86°F dry-bulb, 80.1°F wet-bulb, and 78.2°F dew point. The humidity ratio is 0.021 and the enthalpy is 43.8 Btu/lb dry air.

An alternate method of solution would be to solve Equation 2.14 for h_3.

$$h_3 = \frac{m_1 h_1 + m_2 h_2}{m_1 + m_2}$$

$$h_3 = \frac{(138.8)\ (48.8) + (37)\ (24.5)}{175.8} =$$

43.8 Btu/lb dry air

Then enter the chart at this enthalpy to locate the mixture point on a straight line connecting state 1 and state 2.

ADIABATIC MIXING OF MOIST AIR WITH INJECTED WATER

In many applications it is desired to humidify a stream of moist air by spraying water or steam into the air in order to raise the humidity ratio. If this process takes place adiabatically the energy

balance would be:

$$m_a h_1 + m_w h_w = m_a h_2$$

The increase in humidity ratio would be determined by:

$$m_a W_1 + m_w = m_a W_2$$

$$m_w = m_a (W_2 - W_1)$$

Rearranging and solving for h_w yields:

$$h_w = \frac{h_2 - h_1}{W_2 - W_1} = \frac{\Delta h}{\Delta W} \qquad \text{(Eq. 2.17)}$$

This indicates that the final state point lies on a line whose direction is determined by the initial enthalpy of the injected water and which passes through the initial state point of the moist air.

Referring now to Figure 2.2, it will be noted that the protractor at the upper left has an outer scale of enthalpy/humidity ratio which, by Equation 2.17, is equal to h_w. Thus the protractor can be used to determine the slope of the process line, once h_w has been determined.

EXAMPLE 2.5: It is desired to raise the relative humidity of moist air from 90°F and 20% relative humidity to 60% relative humidity by injecting water at 75°F. What will be the final condition of the air and how much water must be injected for each lb of dry air?

SOLUTION: Refer to the psychrometric chart, Figure 2.6, on which the process line is shown from A to B. The enthalpy of water at 75° is very nearly 43 Btu/lb. This is h_w in Equation 2.17 and is equal to the enthalpy/humidity ratio. On the protractor draw a line, E-F through the initial state, A. The intersection of this line with the 60% relative humidity line locates the final state point, B. From the chart, Figure 2.6, determine the final condition, 72.3° dry-bulb, 63° wet bulb and 56.7° dew point.

The humdity ratio, W_1, at point A, is 0.006 and W_2 at point B is 0.0102.

Then:

$$W_2 - W_1 = 0.0102 - 0.006 = 0.0042 \text{ lb water/lb dry air}$$

which must be injected.

EXAMPLE 2.6: Saturated steam at $212^\circ F$ is sprayed into moist air at 75° dry-bulb and 55° wet-bulb to raise the humidity to 75° wet-bulb. Determine the final dry-bulb temperature and the amount of steam to be added.

SOLUTION: The enthalpy of saturated steam at $212^\circ F$ is 1150.4 Btu/lb, from the steam tables. With this value of h lay in the line E-G on the protractor of Figure 2.6. Parallel to E-G draw a line through the initial state point, C. The intersection of this line with the 75° wet-bulb line is the final state point. From the chart read the final dry-bulb temperature at $79^\circ F$ at point D. The relative humidity will be increased from about 27% to about 83%.

The humidity ratio, W_1, at point C is read as 0.0047 and W_2 at point D, is 0.0179.

$$W_2 - W_1 = 0.0179 - 0.0047 = 0.0132 \text{ lb steam/lb dry air}$$

Notice that in Example 2.6 the dry-bulb temperature increased when steam was sprayed into the air, while in Example 2.5 the dry-bulb temperature decreased when water was sprayed into the air. This is due to the fact that the water must vaporize and, in doing so, absorbs its latent heat from the surrounding air. Thus there is a decrease in the sensible heat and an increase in the latent heat so that the net increase in total heat is very small. The steam is already in the vapor phase and at a temperature well above the temperature of the air. Consequently the temperature rises.

ABSORPTION OF HEAT AND MOISTURE BY MOIST AIR

In air-conditioning calculations the usual problem is to determine the quantity, and condition, of moist air which must be supplied to absorb given

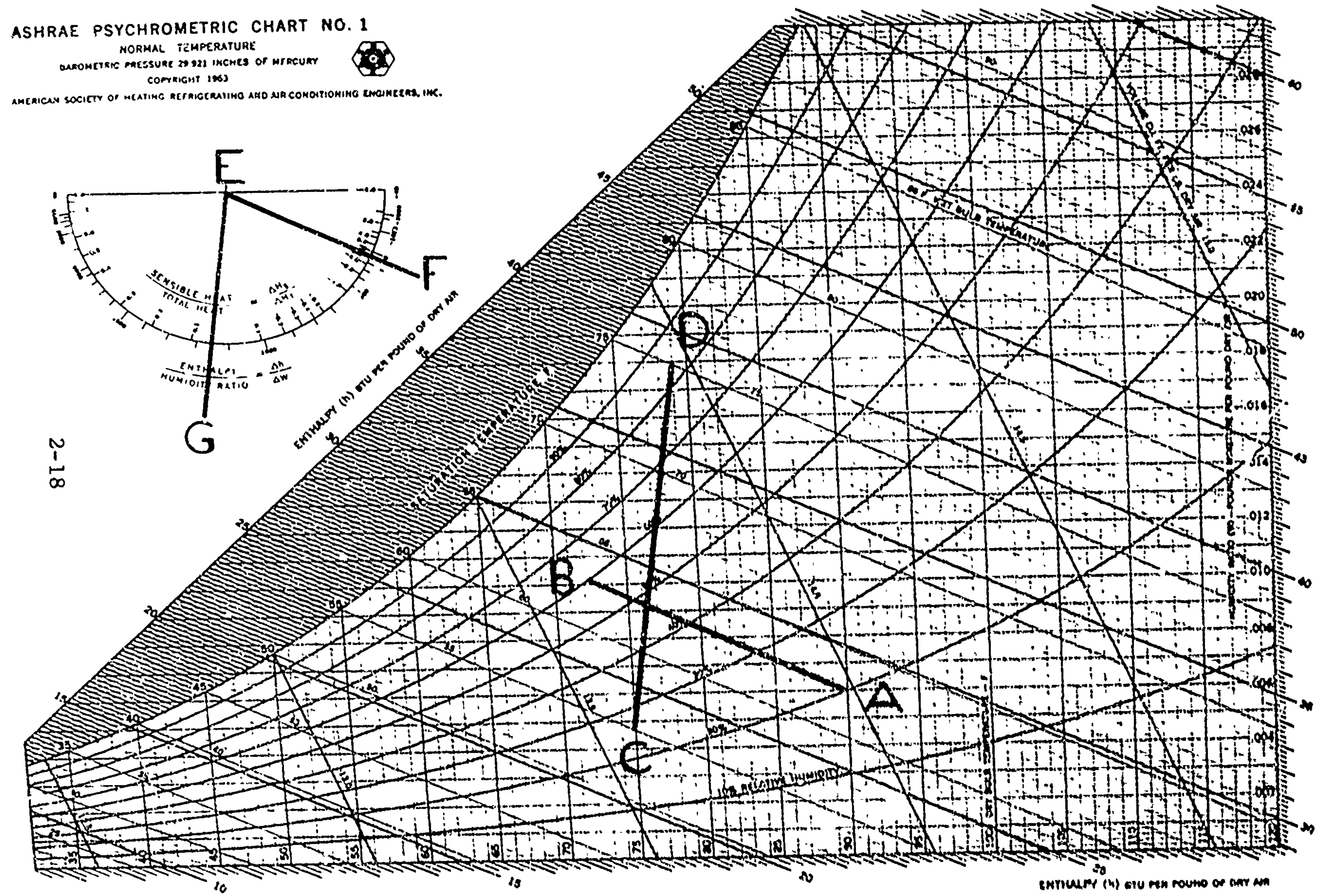

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FIGURE 2.6

amounts of energy and water from a given space. Normally the condition of the air leaving the space is specified.

Energy gains within the space may come from energy transferred across the boundaries and from sources within the space. Those gains which are due to energy addition only, and not due to addition of water, are called the "sensible heat gain." Water or water vapor may also be added across the boundaries of the space or from internal sources. Each pound of moisture adds energy equal to its specific enthalpy. For steady state conditions, the energy balance is:

$$m_a h_1 + Q_s + \Sigma m_w h_w = m_a h_2$$

The moisture mass balance is:

$$m_a W_1 + \Sigma m_w = m_a W_2$$

Where Q_s = sensible heat gain, Btu

$\Sigma m_w h_w$ = latent heat gain, Btu

Σm_w = net sum of all moisture gains, lb

Rearranging gives:

$$Q_s + \Sigma m_w h_w = m_a (h_2 - h_1) \qquad \text{(Eq. 2.18)}$$

$$\Sigma m_w = m_a (W_2 - W_1) \qquad \text{(Eq. 2.19)}$$

and:

$$\frac{h_2 - h_1}{W_2 - W_1} = \frac{Q_s + \Sigma m_w h_w}{\Sigma m_w} \qquad \text{(Eq. 2.20)}$$

This indicates that, for a given state of air leaving the space, all possible conditions of the supply air lie on a straight line drawn, on the psychrometric chart, through the final state point and that the line has a direction determined by the value of the right hand side of Equation 2.20. This line is called the "condition line."

EXAMPLE 2.7: Air is supplied to a space at 60°F dry-bulb and is to leave at 80°F and 50% relative humidity.

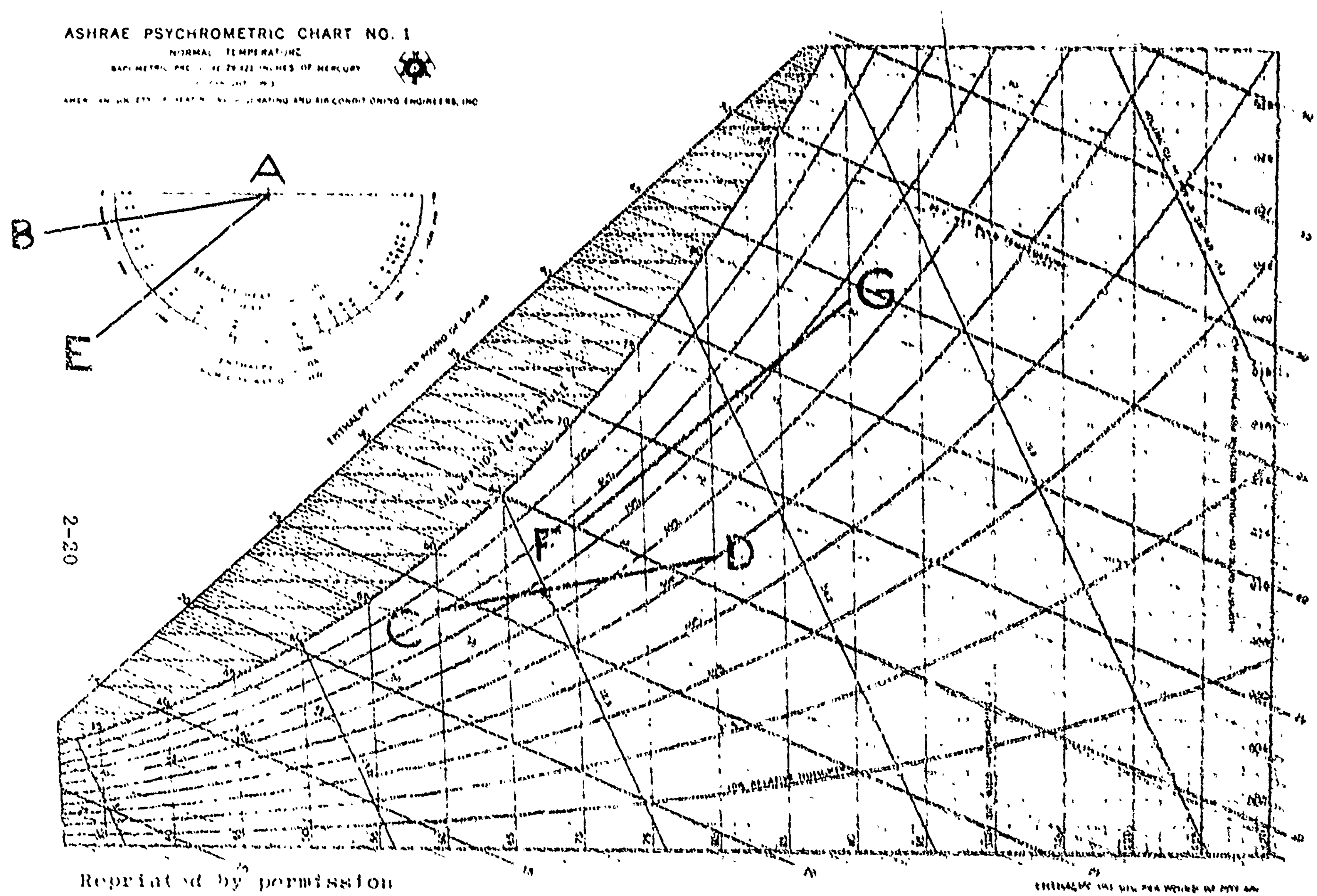

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FIGURE 2.7

The sensible heat gain is 10,000 Btu per hour and 4 lb/hr of water vapor are added by the occupants of the space. Determine the required condition of the supply air and the necessary volume rate of flow.

SOLUTION: The moisture gain from the occupants may be taken as saturated vapor at 90°F with an enthalpy of 1100.44 Btu/lb. From Equation 2.20:

$$\frac{\Delta h}{\Delta w} = \frac{10,000 + 4 \quad (1100.44)}{4} = 3700$$

On the protractor of Figure 2.7, the direction of the condition line, A-B, is established. Then draw C-D through the final state point, D, parallel to A-B. The intersection of this line with the 60° dry-bulb line establishes the condition of the supply air, state point C. From the chart the supply air must be at 55.5° wet-bulb and 81% relative humidity. The specific volume is 13.3 cu ft/lb dry air.

The enthalpy at point C is read as h_1 = 24.1 Btu/lb dry air and at D it is h_2 = 31.1 Btu/lb dry air. The required mass of air is, from Equation 2.18:

$$m_a = \frac{Q_s + \Sigma m_w h_w}{h_2 - h_1} = \frac{10,000 + 4 \quad (1100.4)}{31.1 - 24.1} = 2057 \text{ lb/hr}$$

The volume rate of flow is:

$$\frac{(2057)}{60} \quad (13.3) = 456 \text{ cfm}$$

A very close approximation of the condition line could have been established using the inner scale of the protractor on the psychrometric chart. This scale is the sensible heat/total heat ratio, $\Delta H_s/\Delta H_t$.

From the previous data this ratio is:

$$\frac{\Delta H_s}{\Delta H_t} = \frac{10,000}{14,400} = 0.694$$

It can be seen that this closely approximates the line A-B established by the enthalpy/humidity ratio.

Under some conditions, when cooling by ventilation air, it is required to determine the necessary flow rate of supply air at given conditions to maintain a

desired condition of the air leaving the space. This is illustrated by the following example.

EXAMPLE 2.8: Air is supplied to a space of 70° dry-bulb and 65° wet-bulb. The dry-bulb temperature of the air leaving is not to exceed 90°F. Sensible heat gains to the space amount to 7,000 Btu/hr and the occupants add 12.7 lb of water vapor per hour. Determine the wet-bulb temperature of the air leaving and the volume rate of flow required.

SOLUTION: The enthalpy of the water vapor is again taken as 1100.44 Btu/lb. By Equation 2.20:

$$\frac{\Delta h}{\Delta w} = \frac{7000 + 12.7 \ (1100.44)}{12.7} = 1655$$

or alternately:

$$\frac{\Delta H_s}{\Delta H_t} = \frac{7000}{7000 + 12.7 \ (1100.44)} = 0.333$$

Either of these may be used to establish the condition line, A-E, on the protractor of Figure 2.7. Then through the state point of the supply air, F, draw a line parallel to A-E. The intersection of this line with the 90° dry-bulb line establishes the final condition. From the chart, read the wet-bulb temperature of 80.7°F.

From the chart the specific volume of the supply air is 13.6 cu ft/lb and the enthalpy is 30.0 Btu/lb. The enthalpy of the discharge air is 44.3 Btu/lb. The required mass of air is then:

$$m_a = \frac{21,000}{60 \ (44.3 - 30.0)} = 24.5 \text{ lb/min}$$

The required volume rate of flow is:

$$(24.5)\ (13.6) = 333 \text{ cfm}$$

PRACTICE PROBLEMS

2.1 Moist air is at a dry-bulb temperature of 90°F and a humidity ratio of 0.014. Determine the enthalpy of the mixture (1) from the psychrometric chart and (2) by the use of equations 2.8, 2.9 and 2.10.

2.2 Air is at 85°F dry-bulb and 40% relative humidity. From the psychrometric chart determine the dew point, wet-bulb, humidity ratio, enthalpy and specific volume of the moist air.

2.3 Air is at 80°F dry-bulb and 75°F wet-bulb. From the psychrometric chart determine the dew point, relative humidity, humidity ratio, enthalpy and specific volume.

2.4 Air is at 93°F dry-bulb and 72°F wet-bulb. From the psychrometric chart determine the dew point, relative humidity, humidity ratio, enthalpy and specific volume.

2.5 Air at a dry-bulb temperature of 55°F and a wet-bulb temperature of 50°F is to be heated sensibly until the temperature is 75°F. For an intake air flow rate of 1500 cfm determine the rate at which heat must be added.

2.6 Air at 90°F dry-bulb and 80% relative humidity is passed over a cooling coil which reduces the temperature to 75°F. For a chilled air flow rate of 2000 cfm determine how much heat is removed.

2.7 1500 cfm of fresh air at 55°F and 50% relative humidity is to be tempered with recirculated air at 90°F dry-bulb and 80°F wet-bulb so that the dry-bulb temperature of the mixture is 72°F. How much air must be recirculated?

2.8 A shelter containing 50 persons is ventilated with fresh air at 77°F dry-bulb and 63°F wet-bulb. The equipment sensible heat gain is 12000 Btu per hour and the occupants add 8.65 lb/hr of water vapor. Determine the rate of flow of ventilation air required to hold the dry-bulb temperature of the exhaust air under 85°F. What is the wet-bulb temperature of the exhaust air?

CHAPTER III

PHYSIOLOGICAL RESPONSE TO THE CHEMICAL AND THERMAL ENVIRONMENT

The purpose of a protective shelter is to enable people to survive a threat to their life or well-being. The threat, for purposes of this discussion, is the effects of nuclear weapons, specifically radioactive fallout. It is, however, axiomatic that people must be able to live in the shelter or, in other words, the shelter must provide a habitable environment. Unless this condition is met, no amount of shelter is of any use.

In order to survive a nuclear attack, the population must survive in shelters for varying periods generally up to two weeks. There is nothing in man's experience which can be compared to living under these conditions. The air raid shelters of World War II protected large numbers of people, but only for a few hours. They required almost nothing in the way of facilities or supplies and, since there was no threat of airborne contamination, ventilation was not considered to be a problem. The crews of submarines must live in closed environments for long periods of time, but the submarine is a military weapons system in which are provided all the equipment and facilities necessary to provide a comfortable environment. Furthermore, a submarine operates in the ocean, which provides a heat sink of essentially infinite capacity to aid in the control of the thermal environment. Space capsules are also closed systems, but no expense has been spared to create in them a comfortable environment. Both submarines and spacecraft are occupied only by thoroughly-trained, well-conditioned, carefully-selected crews. On the other hand, a fallout shelter must be operated with an absolute minimum of facilities and equipment and be occupied by a random cross section of the civilian population without previous training or conditioning.

The determination of what is an "absolute minimum" of facilities and equipment will be based on the human tolerance limits of heat, cold, humidity, carbon dioxide and oxygen. The tolerance limits of carbon dioxide and oxygen are the governing factors in the

control of the chemical environment. The tolerance for cold, heat and humidity provide the limitations on control of the thermal environment.

Control of the chemical environment implies control of the composition of the environmental air. For the most part this means supplying air with a sufficiently high oxygen content and a sufficiently low carbon dioxide content to maintain life. It also involves the elimination or control of odorous, toxic, or explosive constituents such as carbon monoxide, hydrocarbon fuel vapors, hydrogen, or other dangerous substances.

The composition of atmospheric air, in percent by volume, near ground level, according to the Smithsonian Physical Tables, is as follows:

Nitrogen.......................	78.09%
Oxygen.........................	20.95%
Argon..........................	0.93%
Carbon Dioxide.................	0.02-0.04%
Water Vapor....................	0.2 -4.0%
Trace amounts of other gases.	

This composition will vary to some extent depending on the concentrations of carbon dioxide and water vapor.

Table 3.1, taken from Reference 2, shows the approximate relationship between energy expenditure, oxygen consumption, carbon dioxide production and the rate of breathing.

The values in the table are based on a representative values of the respiratory quotient (RQ) of 0.83. The RQ is the ratio of carbon dioxide production to oxygen consumption and varies with diet and body chemistry. The value of 0.83 is typical of a healthy person on a normal diet.

TABLE 3.1

ENERGY EXPENDITURE, OXYGEN CONSUMPTION, CARBON DIOXIDE PRODUCTION AND RATE OF BREATHING IN MAN

Physical Activity	Energy Expenditure Btu/hr	Oxygen Consumption cu ft/hr	Carbon Dioxide Production cu ft/hr	Rate of Breathing cu ft/hr
Prone, at rest	300	0.60	0.50	15
Seated, sedentary	400	0.80	0.67	20
Standing, strolling	600	1.20	1.00	30
Walking, 3 MPH	1000	2.00	1.67	50
Heavy Work	1500	3.00	2.50	75

In Table 3.1, note that the rate of breathing for sedentary people is given as 20 cu ft/hr. Since air is approximately 21% oxygen this represents about 4.2 cu ft/hr of oxygen. Yet the oxygen consumption is shown as only 0.80 cu ft/hr. The obvious explanation is that the lungs do not use all the oxygen contained in the air. The data in this table indicate that only about 19% of the oxygen is actually consumed. However, in order to maintain the chemical composition of the air it would be necessary to supply the amount of ventilation air indicated by the rate of breathing data, or about 20 cu ft/hr for each sedentary person. Those who are more active would require more air and would produce more CO_2. This increase might be offset by persons resting in bed or sleeping. For a sleeping person the energy expenditure decreases to about 240 Btu/hr with corresponding decreases in oxygen consumption, carbon dioxide production and rate of breathing.

The minimum rates of ventilation of a shelter will be determined by the tolerance limits of low oxygen concentration and/or excessive CO_2 concentrations. Table 3.2, from Reference 12, summarizes the effects of decreased oxygen concentrations.

TABLE 3.2

EFFECT OF OXYGEN DEFICIENCY

Oxygen Content of Air % By Volume	Effects
20.9	No effects; normal air
15	No immediate effects
10	Dizziness, shortness of breath, deeper and more rapid respiration, quickened pulse, especially on exertion
7	Stupor sets in
5	Minimal concentration compatible with life
2-3	Death within a few minutes

Table 3.3 also from Reference 12, summarizes the effects of excessive carbon dioxide at normal levels of oxygen.

TABLE 3.3

EFFECTS OF CARBON DIOXIDE
(Normal Oxygen Content)

Carbon Dioxide In Air % By Volume	Effects
0.04	No effects normal air
2.0	Breathing deeper, air inspired per breath increased 30 percent
4.0	Breathing much deeper, rate slightly quickened, considerable discomfort
4.5-5.0	Breathing extremely labored, almost unbearable for many individuals, nausea may occur
7-9	Limit of Tolerance
10-11	Inability to coordinate, unconscious ness in about ten minutes
15-20	Symptoms increase but probably not fatal in one hour
25-30	Diminished respiration; fall of blood presure;coma;loss of reflexes, anesthesia; gradual death after some hours

The data from the preceding tables must be applied with caution since there are wide variations in individual tolerances. Also the data given is for healthy adults. The literature contains almost no information on the tolerances of the very young, the aged, or persons in ill health. It appears obvious the persons with respiratory ailments would have decreased tolerance, especially to excessive carbon dioxide. It must also be kept in mind that the tables give the effects of decreased oxygen with normal CO_2 and of increased CO_2 with normal oxygen whereas, in a shelter, it would be expected that the CO_2 would increase as oxygen decreased.

The tables summarize the physiological effects of decreased oxygen and increased carbon dioxide. They do not, however, provide information on the length of time during which the conditions would exist. An altered chemical composition of the air which could be tolerated for a short period might be more dangerous if protracted over a longer period of time since the effects of the gases are a function of both time and the concentration. For example, concentrations of carbon dioxide of up to 2 or 3 percent could be tolerated by most persons for one to two hours with some discomfort but no permanent harm. If, however, the exposure were continued over a longer period of time the physiological effects would become more severe and could exceed the tolerance level of some people.

For reasons cited above, there is some divergence of opinion concerning safe levels of oxygen and carbon dioxide to be maintained in a shelter, for prolonged occupancy. There is reasonably general agreement that the oxygen concentration should not be less than 17 percent by volume. Various investigators recommend maximum allowable carbon dioxide concentrations ranging from 0.6 percent to 7.2 percent. Experience in submarines during World War II and subsequent experiments established the necessity to keep the CO_2 concentration at or below 1 percent for continuous exposure.

Based on these, and other considerations, the recommended tolerance levels for prolonged shelter occupancy should be not less than 17 percent oxygen concentration and not more than 0.5 percent carbon dioxide concentration.

A ventilation rate of 0.4 cfm per person of fresh air will maintain the oxygen at 17 percent: However it requires about 2.8 cfm per person to limit the carbon dioxide build-up to 0.5 percent. Thus the environment will reach the limiting concentration of carbon dioxide before the oxygen has been depleted to any great extent.

The above considerations are the basis for the present requirement of a minimum ventilation rate of 3 cfm per person.

In consideration of the effects of the chemical environment it would be well to include carbon monoxide even though the amount of this gas produced by the body is negligibly small. It results from the incomplete combustion of carbon in fuels. In confined shelter spaces the prime source of CO would be tobacco smoking, with pipes producing five times and cigar almost 20 times as much as cigarettes. It can also come from fuel burning devices in the shelter, from the exhaust gases of internal combustion engines or could be drawn into the ventilation intake from smoldering fires outside the shelter.

Carbon monoxide is insidious in its action since it is invisible, odorless, tasteless, and non-irritating. The human tolerance to CO is very slight. For industrial purposes the allowable concentration is considered to be 100 parts per million (ppm) which is equivalent to 0.01 percent by volume. This is based on an 8-hour workday, five days per week. For exposure over longer sustained periods lower limits are used. For submarines the limit is 50 ppm or 0.005 percent and for space cabins the design level is 10 ppm or 0.001 percent.

Table 3.4 and Figure 3.1 summarize the effects of carbon monoxide on humans. (83)

TABLE 3.4

EFFECTS OF CARBON MONOXIDE

Carbon Monoxide In Air % By Volume	Effects
0.01	Maximum allowable concentration for industrial ventilation, based on 8-hour exposure each work day
0.02	Possible mild frontal headache after two to three hours
0.04	Frontal headache and nausea after one to two hours; occipital (rear of head) headache after two and one-half to three and one-half hours
0.08	Headache, dizziness, and nausea in forty-five minutes; collapse and possible unconsciousness in two hours
0.16	Headache, dizziness, and nausea in twenty minutes; collapse, unconsciousness, and possible death in two hours
0.32	Headache and dizziness in five to ten minutes; unconsciousness and danger of death in thirty minutes
0.64	Headache and dizziness in one to two minutes; unconsciousness and danger of death in ten to fifteen minutes
1.28	Immediate effect; unconsciousness and danger of death in one to three minutes

Increased levels of carbon dioxide would require lowering the acceptable concentration of carbon monoxide. As indicated in Table 3.3, the increased CO_2 results in deeper and more rapid breathing which, in turn, increases the absorption of CO into the body.

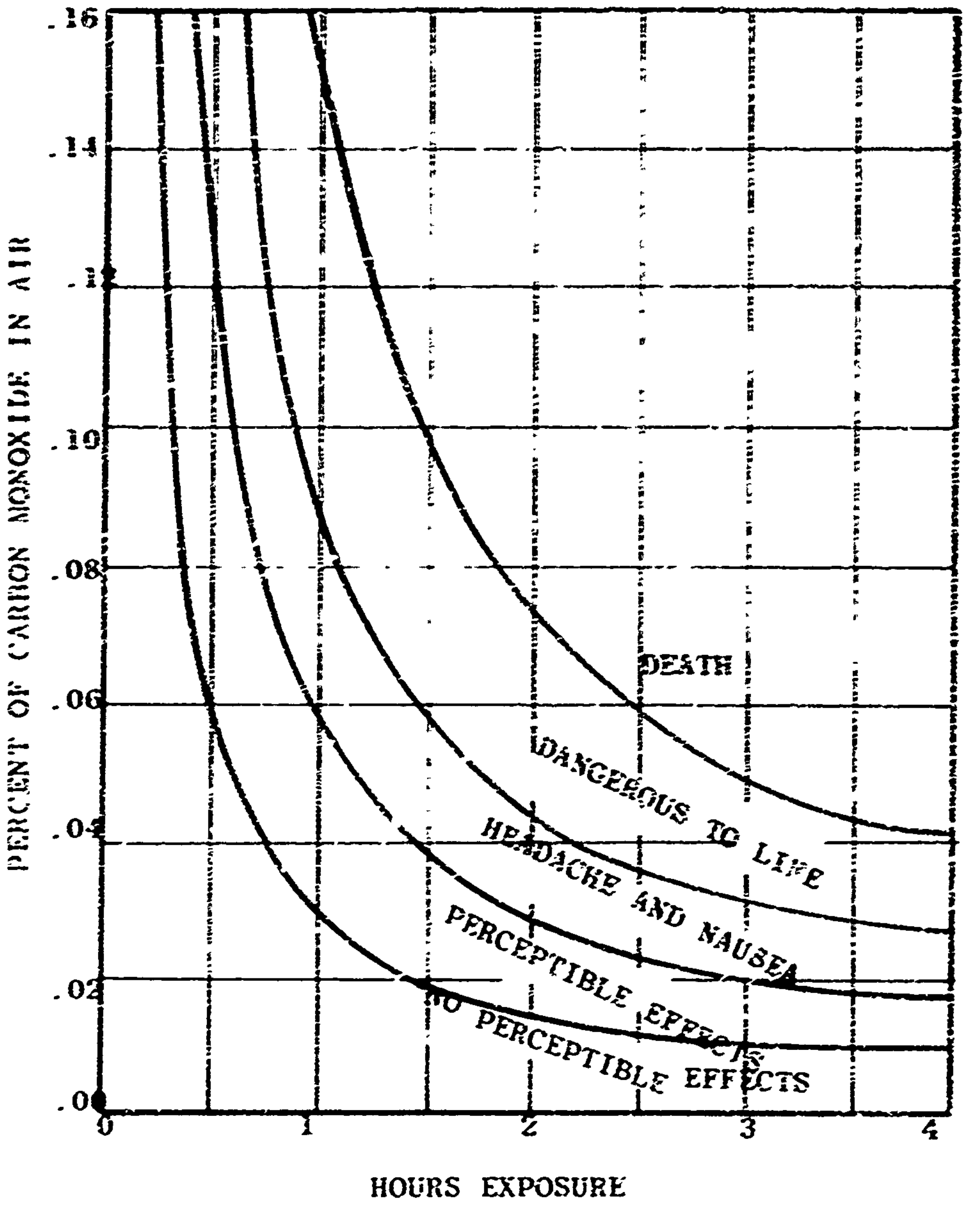


Figure 3.1-Effects of Carbon Monoxide for a Give Time On Human Beings

There is no really satisfactory method of removing carbon monoxide from the air. It is, therefore, necessary to remove the contaminated air and replace it with fresh air. Fortunately the minimum ventilation rate of 2 cfm per person should be adequate to prevent serious build-up of carbon monoxide. It may, however, be desirable to place some restrictions on smoking in the shelter when ventilation is at the minimal rate. In cases where CO from smoldering fires may be drawn into the ventilation intake it may become necessary to close down and seal off the ventilation system. Under these conditions it will probably be necessary to place strict limitations on the amount of smoking permitted in order to prevent excessive increases in carbon monoxide. Other problems arising from such "buttoned up" operation are discussed in Chapter X.

The physiological response of the human body to the thermal environment depends on the thermodynamic processes of heat exchange between the body and the environment. The heat balance equation for the body may be expressed as:

$$S = M - E \pm R \pm C \qquad \text{(Eq. 3.1)}$$

Where S = the rate of heat storage in the body and may be either positive or negative

M = rate of metabolism; heat produced within the body

E = rate of evaporative heat loss

R = rate of radiation heat loss or gain

C = rate of convective heat loss or gain

Where S is zero the body is in a state of thermal equilibrium. If this is accomplished without activating the thermoregulatory mechanisms of shivering, sweating, or strong vasomotor* activity, thermal comfort exists. If S is negative there will be a decrease in stored energy and a cold stress will be imposed on the

---

*Vasomotor: regulating the tension and size of blood vessels.

body: the body tissues will be chilled and the body temperature will decrease. Conversely, when S is positive there will be an increase in stored energy, and a heat stress will be imposed; the body temperature will increase and the body tissue will be heated.

The rate of metabolism, M, is the rate at which energy is being converted in the body, from the chemical energy of food to heat and/or work. At any given time the metabolic rate will be determined, for a given individual, by factors which include the amount of work being done, the amount and type of clothing, and the temperature of the environment. In addition the rate will vary between individuals on the basis of age, size, sex, race, acclimatization and habits.

Table 3.5 is taken from Reference 13 and indicates the variation in metabolic rate with activity. The values in the table apply for a 154 pound man.

TABLE 3.5

ENERGY METABOLISM FOR VARIOUS TYPES OF ACTIVITY

Kind of Work	Activity	M Btu/hr
	Sleeping	250
	Sitting quietly	400
Light Work	Sitting, moderate arm and trunk movements (desk work, typing)	450-550
	Sitting, moderate arm and leg movements (playing organ, driving car in traffic)	550-650
Moderate Work	Sitting, heavy arm and leg movements	650-800
	Standing, light work at machine or bench, some walking	650-750
	Standing, moderate work at machine or bench, some walking	750-1000
	Walking about with moderate lifting or pushing	1000-1400
Heavy Work	Intermittent heavy lifting, pushing or pulling (pick and shovel work)	1500-2000
	Hardest sustained work	2000-2400

Metabolic rates much higher than those given in the table have been reported. A rate of 4880 Btu/hr has been recorded for rowers in a crew race. This produced exhaustion in 22 minutes. A reported rate of 15,600 Btu/hr produced complete exhaustion in 22 seconds.

The highest sustained rate for an eight-hour period would be in the order of about 1500 Btu/hr for a seasoned worker. A trained athlete might sustain 1600 Btu/hr or a little more.

Table 3.6 presents variation in the sensible and latent heat portions of the metabolic losses with dry-bulb temperature, as contained in Reference 20.

The most probable values of sensible and latent heat losses applicable to shelter design are under investigation by the U. S. Public Health Service. Pending the results of various investigations it is recommended that the values in Table 3.6 be used.

TABLE 3.6

METABOLIC HEAT LOSSES FOR SEDENTARY ADULTS

Dry - Bulb Temperature °F	Sensible Heat Loss Btu/hr	Latent Heat Loss Btu/hr	Moisture Evaporated lb/hr
50	335	65	0.062
60	330	70	0.067
70	300	100	0.096
80	220	180	0.173
90	115	285	0.274
100	0	400	0.384
110	-120	520	0.499

The evaporative heat loss, E, is divided into two processes; insensible perspiration and sweating. The insensible perspiration is the diffusion of moisture from the deeper layers of the skin and from the moist surfaces of the respiratory system. Even for a person at rest in a comfortable environment about 24 percent of the total heat loss from the body is insensible perspiration.

The evaporative heat loss increases to about 40 percent of the total heat loss for light work and walking slowly, and to about 60 percent for heavy work.

Evaporation of water from the surface of the skin occurs within a few millimeters of the surface so that all the heat required for vaporization is supplied by the skin. The rate of heat loss, E, is proportional to the body area involved, the saturated vapor pressure at skin temperature, the saturated vapor pressure at air temperature, and the relative humidity of the air. When the relative humidity multiplied by the saturated vapor pressure at air temperature ($\phi \times P_s$) is equal to the saturated vapor pressure at skin temperature, the evaporative heat loss becomes zero. In other words the partial pressure of the water vapor in the air is equal to the vapor pressure at the skin temperature, and there is no pressure differential to cause vaporization.

Radiation heat exchange will take place between the body (or clothing) surface and the surrounding surfaces: walls, ceiling, floor, furniture, other bodies, etc. The rate of heat transfer is proportional to the difference in the fourth powers of absolute temperatures of the surfaces and the body. If the surfaces are at a lower temperature than the body surface, the transfer will be from the body to the surface (negative R). If the surface is at a higher temperature the transfer will be to the body (positive R).

In the usual case the body will be exposed to several surfaces at different temperatures and from various directions. In this situation the radiation gain or loss from each surface must be calculated separately or a mean radiant temperature must be determined, which is, in effect, an average for all the surfaces. As a matter of practical application in a shelter there would be no very hot or very cold (with respect to body temperature) surfaces so that the radiative heat exchange would be insignificant.

Convection heat exchange with the air depends principally on the temperature difference between the body surface and the air and on the air velocity. If the body surface temperature is greater than the air temperature heat will be transferred from the body to the air. If, on the other hand, the air temperature

is greater than the body surface temperature heat will be transferred from the air to the body. Note in Table 3.6 that the sensible heat loss becomes negative at dry-bulb temperatures over 100°F indicating sensible heat transfer to the body. For thermal equilibrium the latent heat loss must increase to dissipate this additional heat.

ENVIRONMENTAL AND PHYSIOLOGICAL STRAIN INDICES

For many years there have been attempts to devise reliable indices to express comfort and physiological strain effects as single numbers. Because of the many variables involved in environmental conditions and human physiological reactions no index has been developed which is reliable for all conditions. Some of the following indices indicate comfort or a subjective reaction to environmental conditions while others are measures of physiological strain.

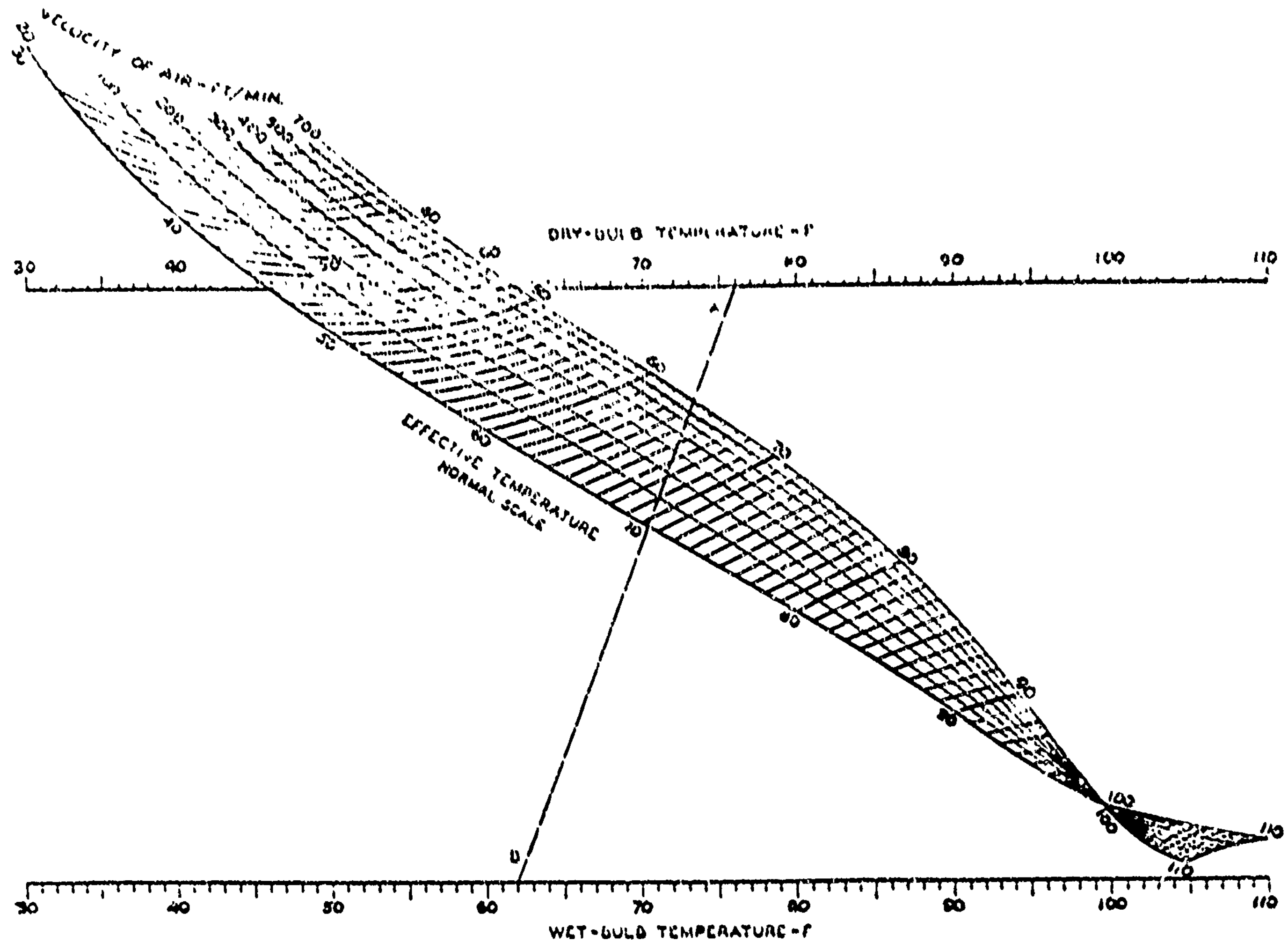
EFFECTIVE TEMPERATURE:

One of the most widely used indices, and the one most commonly applied for shelter conditions, is the effective temperature (ET) developed by a research team of the American Society of Heating and Ventilating Engineers (ASHVE, now ASHRAE). Test subjects were exposed to atmospheres with different temperatures, humidities, and air movements and were asked to make comparative ratings of their sensations of warmth and coolness. The reactions were subjective and required statistical analysis before the index was determined. This index is presented in the form of a nomogram in the ASHRAE Guide and Data Book which is reproduced as Figure 3.2. From this nomogram the ET may be determined given the dry-bulb and wet-bulb temperatures and the air velocity.

The effective temperature may also be approximated by the empirical equation:

$$ET = 0.4\ (WBT + DBT) + 15 \qquad \text{(Eq. 3.2)}$$

Values determined by this equation will agree within one or two degrees with those read from the nomogram, for air velocity of 20 feet per minute.



HOW TO USE THE CHART: Draw line A-B through measured dry-bulb and wet-bulb temperature. Read effective temperature or velocity at desired intersections with line A-B. EXAMPLE: Given 67 F db and 62 F wb, read: 69 ET at 100 fpm velocity, or 340 fpm required for 66 ET.

Fig. 3.2...ASHRAE Chart for Determining Effective Temperature for Sedentary Individuals, Normally Clothed

(Reprinted by Permission)

The effective temperature index, like any other method, is not completely accurate and must be applied with care.

1. The basic observations were made with a specific group of people, namely healthy, young, white, Americans, and do not necessarily apply to groups which do not conform to these specifications.
2. The observations relate only to sedentary conditions.
3. The index applies to normally clothed persons. Heavy clothing would be expected to reduce the effect of air movement.
4. The ET index is most applicable to conditions where radiation effects are negligible.
5. It does not apply for air movements less than 20 FPM.
6. At the upper end of the scale, above 90 ET, the index is not reliable since subjective sensations of heat are not very good guides under conditions as hot as this.
7. The scale makes too much allowance for humidity at low temperatures and not enough allowance at high temperatures.
8. The ET is based on sensations of warmth and coolness. It provides no means for determining the physiological strain.

In Figure 3.4 is shown a revised ASHRAE comfort chart which indicates the proportion of the test population that could be expected to be comfortable at various effective temperatures. This chart indicates that in the summer the maximum number of people would feel comfortable at 71^{o}FET with the percentage reaching zero at 79^{o}FET. An effective temperature of 78^{o} is generally accepted as the perspiration threshold.

<u>OPERATIVE TEMPERATURE (OT)</u>: The operative temperature is a measure of the net thermal effects of radiative and convective heat transfer, based on equation 3.1. It includes the effects of dry bulb temperature, air motion, mean radiant temperature and body surface temperature, but does not include effects of humidity. If the mean radiant temperature is approximately equal to the dry bulb temperature, the OT approximates the air temperature.

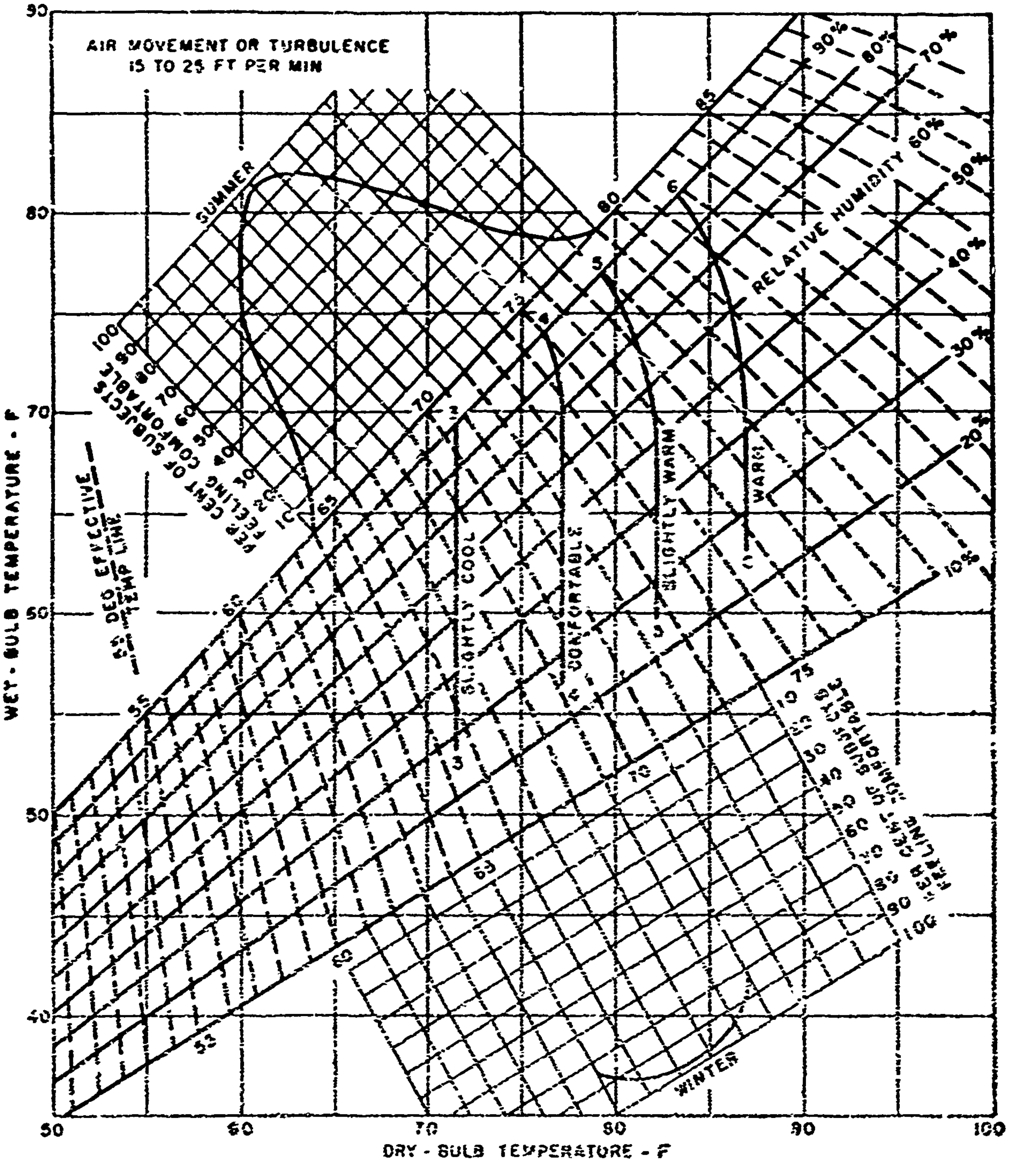


Fig. 3.3...Revised ASHRAE Comfort Chart

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WET-BULB GLOBE-TEMPERATURE INDEX (WBGT): The measurement of air velocities for the determination of effective temperature is a difficult procedure. The ET also does not take into account any radiant heat. The WBGT index suggests the use of a black globe instead of a dry bulb thermometer since the globe temperature will reflect the effects of air movement provided that radiant heat is present.

The WBGT reading is obtained from:

$$WBGT = 0.7\ WBT + 0.3\ GT \qquad \text{(Eq. 3.3)}$$

Where WBT is the wet-bulb temperature and GT is the globe temperature.

INDEX OF PHYSIOLOGICAL EFFECT (EP): This index is determined by increase in heart rate, skin temperature, rectal temperature, and sweat rate. On the basis of experimental investigations contour curves representing lines of equal physiological strain were plotted on charts of dry-bulb vs. wet-bulb temperature. To use these charts it is necessary to know the metabolic rate. When EP is less than 200, thermal equilibrium is possible. When EP is over 250 heat is stored in the body and when EP is over 400 conditions are intolerable. The air velocity used in establishing EP was 180 FPM.

PREDICTED FOUR-HOUR SWEAT RATE (P^4SR): This index uses only rate of sweating as the criterion of heat stress in environments hot enough to cause sweating. Based on experiments by the British, empirical nomograms have been constructed for predicting the sweat rate of fit, acclimatized young men exposed to various environments.

BELDING-HATCH HEAT STRESS INDEX (HSI): The HSI expresses the heat stress in terms of the amount of sweat which must be evaporated to maintain heat balance (S = 0 in Eq. 3.1) compared to the maximum possible evaporative heat loss at an arbitrarily assumed skin temperature of 95°F. An HSI of zero indicates no thermal strain.

RELATIVE STRAIN (RS): Lee and Henschel (11) propose an index which they call relative strain. It is a modification of HSI based on experimental data from

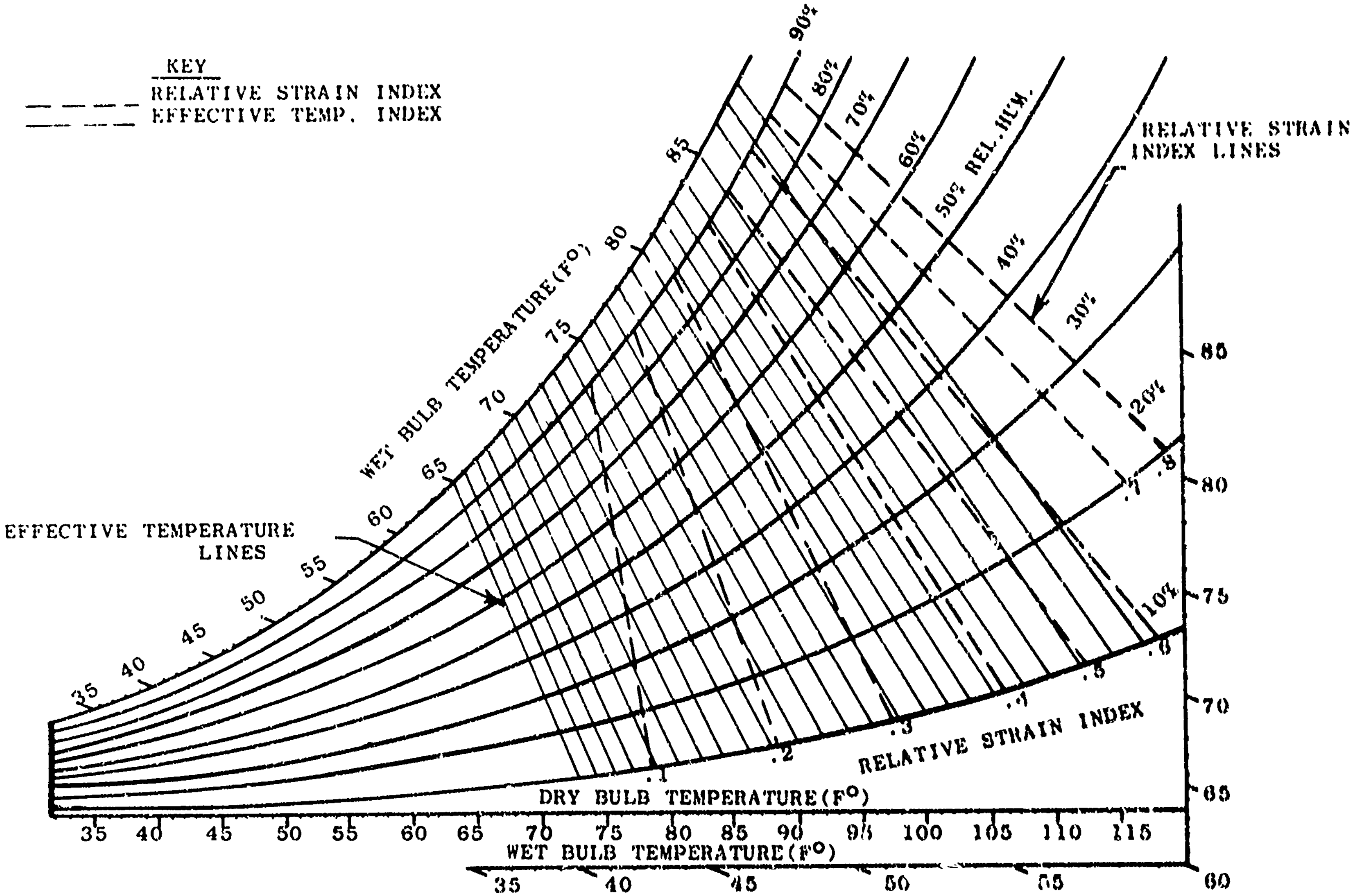


Figure 3.4-Comparison of Relative Strain Index and Effective Temperature Index with Wet and Dry Bulb Temperature

the literature. For each value of relative strain from zero (no strain) through 1 (maximum theoretically tolerable strain), to higher values (heat storage in the body), a straight line can be drawn on the psychrometric chart and compared to the ET lines as shown in Figure 3.4. At the lower temperatures, the RS lines are steeper than the ET lines, indicating that the RS is less affected by humidity. At the higher temperatures the opposite is true, indicating a greater effect of humidity on RS than on ET. Thus, the RS index appears to answer the objection to the ET index of not sufficient allowance for humidity at higher temperatures.

Reference 11 presents a chart of significant effects of RS for a specified standard condition. The standard individual is taken as a healthy male about 25 years of age not acclimatized to heat. Standard conditions are taken as activity equivalent to walking at 2 MPH, in a light suit, with air velocity of 100 FPM and wall temperature equal to air temperature.

The reference also presents charts showing significant effects of RS for some non-standard individuals. The time of exposure to the stress is taken to be about 24 hours. The responses from these charts have been interpreted in the form of Table 3.7 which has been taken from Reference 4.

PHYSIOLOGICAL ADJUSTMENT TO HEAT STRESS

When a heat stress is imposed on the human body, the blood flow to the skin is increased due to dilation of blood vessels. Obviously the increased blood volume to the skin must result in increased volume of blood flow or restriction of flow in other areas in order to maintain adequate blood pressure. Both methods are used by the body.

The main protection against heat stress is the activation of the sweat glands, wetting the body surface and increasing the heat loss by evaporation. The rate of sweating varies with the individual, and the degree of acclimatization.

TABLE 3.7

PHYSIOLOGICAL RESPONSE TO ELEVATED
EFFECTIVE TEMPERATURES

Type of Individual	Effective Temp., °F 75	78	80	85	86
Acclimated	C	C	W	W	SD
Healthy 25 year old males	C	W	SD	AD	F
45-65 years old	C	SD	AD	F	
65 and older	C	SD	F		
Infants	C	AD	F		
Obese	C	SD	F		
Limited water (less .3 liters)	C	SD	F		
Metabolic Disorders	C	W	AD	F	
Skin Disorders	C	W	F		
Heart and lung disorders	C	SD	F		
Stomach Disorders	C	W	F		
Mental abnormalities	C	AD	F		

C - Comfortable

W - Warm

SD-Some Distressed

AD-All Distressed

F - Failure (a term analogous to the military concept of a casualty)

The three principal effects of heat stress are heat cramps, heat exhaustion and heat stroke. Of these, heat cramps is the least severe in that most of the physiological systems remain intact. It results from salt depletion and is characterized by severe muscle cramps and a warm, moist skin. The body temperature and blood pressure remain normal. It is more common in the younger age groups but can occur at any age. Rest in a cool environment and ingestion of salt will usually correct the condition.

Heat exhaustion results from the loss of vasomotor control of the blood vessels. The skin would be pale, cold and clammy and the body temperature would usually be sub-normal, but might be normal or elevated. The blood pressure would be below normal. This condition results from a collapse of the circulatory system and is, therefore, more serious than heat cramps. It can occur at any age but is more common among the elderly. Rest in a cool envi nment, salt and water will usually correct the condition although more extensive treatment and medication may be necessary in some cases.

Heat stroke is the most serious of the three possible effects of heat stress since it results from a failure of the thermoregulatory mechanism. The subject will have ceased to sweat and the skin would be flushed, hot and dry. The blood pressure would be elevated. If the condition is continued there can be a collapse of the cardio vascular system. The main symptoms are high fever, delirium, stupor and coma. Treatment consists of iced water bath or wet sheets with fanning and prolonged rest. If professional medical help is available drugs and/or medication may be administered.

Under normal circumstances, heat stroke is relatively uncommon and strikes usually among the elderly or debilitated persons. However, even under conditions where medical help is available, the mortality rate is probably greater than 50 percent.

Loss of water by evaporation reduces the liquid volume at a time when an increase is needed. In order to avoid a reduction in tolerance to heat stress the water must be replaced. A water loss of one to two percent of body weight will result in increased heart rate and increase in rectal temperatures. It is to be expected, therefore, that water consumption will increase during exposure to heat stress.

If the heat regulating system cannot eliminate all of the metabolic energy, heat will be stored in the body, causing the body temperature to rise. A brain temperature of about 108°F will probably be fatal, but prolonged temperatures of 106°F are considered dangerous. A maximum body temperature rise of two to three degrees F is considered to be the physiological limit for healthy persons.

The physical reactions of the body to heat stress are definitely affected by acclimatization. Persons used to living and working in hot environments have a greater tolerance for heat stress due to adjustments made by the body. However a person does not acquire tolerance through heat exposure alone, but only if he also performs work. In shelter tests no evidence has been found to indicate that heat tolerance improved with time. This is due to the fact that work levels of sufficient intensity and duration to improve heat tolerance are generally not feasible under shelter conditions. Also the increase in metabolic output while performing work would increase the environmental heat load and thus offset any advantage to be gained by any improvement in tolerance.

It can be concluded that heat acclimated persons will tolerate higher environmental conditions than those not heat acclimated before developing heat strain but that conditions in the shelter will not, of themselves, be conducive to acclimatization.

Investigations have shown that certain healthy persons at rest can tolerate daily exposures up to 90°FET for several hours provided they can get a good night's sleep in a cooler environment. The highest ET for restful sleep in warm weather was found to be 78°, coinciding with the perspiration threshold. Both human and simulated occupancy tests have shown that the fluctuation of shelter effective temperatures with the diurnal cycle is only on the order of plus or minus two degrees from the average. Thus there would generally be little likelihood of having a nighttime effective temperature of 78° if the daytime ET reached 90°.

In summary it can be said that below 78° to 80° FET, but above the range where cold stress begins, there is little probability of widespread environmental strain. About 82° to 85°FET the problems of heat stress become

more severe and widespread. An ET of 79° at high humidity represents the threshold for the incidence of heat rash, an indication of the continuous presence of unevaporated perspiration on the skin and the beginning of the breakdown of cooling by evaporation.

The earlier literature on environmental conditions in survival shelters has considered 85°FET to be the upper tolerance limit for healthy persons. It has been, however, generally admitted that persons with certain physical disorders, the aged and the very young would experience difficulties. The deleterious effects would include anxiety, sleeplessness, nausea, heat rash and irritability. It might be noted that about 40 percent of the population of the United States is in the age groups below 5 years and above 45 years of age and could not be classified as healthy adults.

Based on considerations outlined above the Office of Civil Defense has adopted the following criteria for environmental conditions in shelters. (4)

> "Sufficient ventilation should be provided to assure at least a 90% reliability of not exceeding 82° F Effective Temperature."

The "reliability" of ventilation system is the percentage of the year during which the specified conditions will be maintained.

PHYSIOLOGICAL ADJUSTMENT TO COLD STRESS

When the body is exposed to a cold stress the blood vessels of the skin constrict, reducing the flow of blood. This decreases the heat transfer from the interior of the body and reduces the heat loss by radiation and convection. The evaporative heat loss will also be reduced.

If the constriction of the blood vessels does not establish a heat balance, shivering will occur causing an increase in metabolism to balance the heat loss. If a heat balance is still not attained, the body temperature will begin to decrease. As the deep body temperature, closely approximated by the rectal temperature falls below 90°F (from a normal temperature of 98-99°F) the shivering mechanism begins to fail and may cease at temperatures of 80-86°F. Further reduction could be fatal if prolonged over a long period.

For practical purposes, people will adjust to cold stress by putting on more clothing, if it is available, and by increasing their level of activity to increase their metabolic rate.

The problem of cold stress in a survival shelter probably will not be serious because of the crowded conditions. In extremely cold weather it may be necessary to decrease ventilation rates in order to prevent an uncomfortably low effective temperature. This, however, should cause no difficulty unless the rate is decreased below that necessary for adequate control of oxygen and carbon dioxide concentrations.

PRACTICE PROBLEMS

3.1 50 persons occupy a shelter in which the dry-bulb temperature is 80°F. How much heat would these persons add to the shelter environment if 20 of them were resting in bunks, 20 were sitting quietly, 8 were moving about and 2 were operating a manual ventilation blower? What would be the total oxygen consumption and carbon dioxide production?

3.2 If all 50 persons in the shelter in Problem 3.1 were sedentary, determine the total heat added to the environment and the sensible and latent heat portions. How much moisture is evaporated into the air?

3.3 Determine the effective temperature, by use of Figure 3.2 and by equation 3.2, for each of the following conditions.

(a) 90°F dry-bulb and 80°F wet bulb
(b) 78°F dry-bulb and 70°F dew-point
(c) 85°F dry-bulb and 65% relative humidity
(d) 82°F dry-bulb and 75°F wet-bulb
(e) 65°F dry-bulb and 60°F wet-bulb
(f) 100°F dry-bulb and 50% relative humidity

3.4 At the following dry-bulb temperatures determine the wet-bulb temperature and relative humidity necessary to maintain an effective temperature of 82°F (Air velocity less than 20 fpm).

(a) 85°F
(b) 88°F
(c) 92°F
(d) 103°F
(e) 97°F
(f) 108°F

3.5 Repeat Problem 3.4 for an 80°F effective temperature.

3.6 Repeat Problem 3.4 for an 85°F effective temperature.

CHAPTER IV

VENTILATION REQUIREMENTS

Unless a method of controlling the physical environment is provided in the shelter system, the transient conditions will either approach an equilibrium state within the accepted limits of toleration or they will exceed those limits. Conditions could become intolerable due to excessive carbon dioxide concentration, low oxygen content (or both) or to excessive effective temperature. Any one of these conditions, or a combination of the three, could cause a serious physiological hazard requiring prompt remedial action. If remedial action is not possible, it would probably require that the shelter be abandoned.

The most fundamental method of controlling the chemical and thermal environment is by ventilation with fresh air. The two aspects of environmental control, chemical and thermal, can be considered as separate problems, although, in general, when the thermal environment is under control the chemical environment will be maintained well within the tolerance limits.

CONTROL OF THE CHEMICAL ENVIRONMENT

In Chapter III it was shown that the limiting concentration of CO_2 for long time periods is about 0.5 percent by volume, with higher percentages permissible for short time exposure. Oxygen concentration for prolonged exposure was shown to be 17 percent or higher. In general the carbon dioxide will reach the limiting concentration before the oxygen is reduced below safe levels.

A ventilation rate of 3 cfm per person will be adequate to maintain the chemical composition of the air within the specified tolerances. Ventilation of the shelter space can occur by infiltration, natural ventilation or by mechanical ventilation. Any of the three methods could, under the proper circumstances, provide sufficient fresh air to control the chemical environment. However fallout shelters would probably have a limited amount of infiltration and other types of protective structures might permit none at all. The amount of ventilation by gravity circulation is, at best, minimal for shelter areas in basements and other

belowground locations. Natural ventilation may, however, be entirely adequate for the midfloors of high-rise buildings. In essence, however, this discussion is concerned with mechanical or forced ventilation.

Under certain conditions it may be necessary to shut down a mechanical ventilation system completely. Such conditions might be (1) excessive concentrations of carbon monoxide in the ventilation air due to fires or smoldering rubble near the air intake; (2) chemical or biological agents in the ambient air; or (3) excess concentration of fallout particles which could be entrained in the ventilation air. There is also the ever-present possibility of breakdown of the mechanical equipment, although, in this case, the ventilation system would not be "buttoned up" and some natural ventilation might be possible.

If no replacement air from outside is available, a closed shelter will remain habitable for only a few hours, unless some internal method is provided for supplying oxygen and removing carbon dioxide. (Systems and methods for accomplishing this will be discussed in Chapter X.) The permissible stay time will be determined by the time required for carbon dioxide to reach the limiting concentration. If the button-up period is to last no more than 24 hours, this concentration may be taken as 3.0 percent.

The stay time can be determined from a simple equation:

$$T = 0.04\ V/N \qquad \text{(Eq. 4.1)}$$

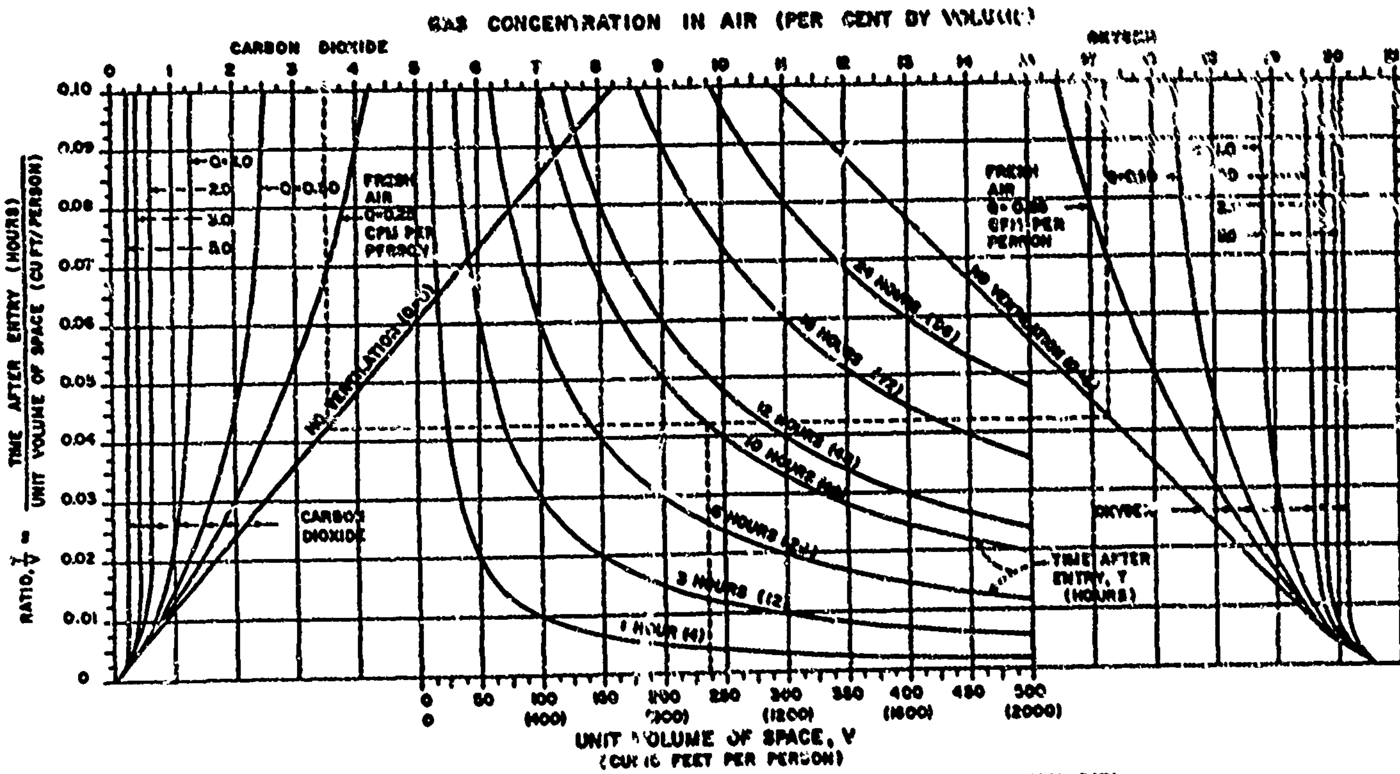
Where:

T = time to reach 3 percent CO_2, hours

V = net volume of space, cu ft

N = number of occupants

Thus, in order to have a button-up capability of 24 hours, it would be necessary to provide 600 cubic feet of space per person. Recall that the National Shelter Survey uses 65 cubic feet per person as one of the criteria, and it can be seen that it is unlikely that a shelter would have anywhere near a



TERMINAL VALUES OF GAS CONCENTRATION

RATE OF VENTILATION (CFM/PERSON)	TERMINAL CONCENTRATION (PERCENT BY VOLUME) CARBON DIOXIDE	OXYGEN
0.25	5.35	14.15
0.50	2.67	17.23
1.00	1.35	18.77
2.00	0.69	19.53
3.00	0.47	19.79
5.00	0.29	20.11

FRESH AIR QUANTITIES CORRECTED TO STANDARD DENSITY OF 0.075 LB/CU FT.

PHYSICAL DATA

OXYGEN CONSUMED = 0.90 CU FT/HR/PERSON *
CARBON DIOXIDE PRODUCED = 0.75 CU FT/HR/PERSON *
MOISTURE LOSS FROM BODY = 0.144 LB/HR/PERSON
OXYGEN IN FRESH AIR = 20.62% BY VOLUME
CARBON DIOXIDE IN FRESH AIR = 0.03% BY VOLUME
DRY-BULB TEMPERATURE = 77°F = 25°C
RELATIVE HUMIDITY OF FRESH AIR = 50%
BAROMETRIC PRESSURE = 760 MM OF HG
* REFERRED TO DENSITY AT 0°C, 760 MM OF HG

CARBON DIOXIDE AND OXYGEN IN OCCUPIED SPACES

FIGURE 4.1

24 hour closure capability, unless a life support system is provided.

Figure 4.1 can be used to determine the stay time for various conditions. It was taken from Reference 2 and shows the relationship between concentrations of carbon dioxide and oxygen,the rate of ventilation per person, the net volume of space per person, and the time after entry. The terminal values of carbon dioxide and oxygen concentration are charted for various ventilation rates, based on oxygen consumption of 0.90 cu ft/hr/person and carbon dioxide production of 0.75 cu ft/hr/person. These values would be representative of persons in confined quarters.

The example, shown by dotted lines, indicates that a carbon dioxide concentration of 3.5 percent by volume will develop in 10 hours in an unventilated shelter having a net volume of 235 cu ft/person. The oxygen content of the air will then be 16.25 percent by volume.

A ventilation rate of 1.5 cfm per person will maintain carbon dioxide at about one percent and oxygen at slightly over 19 percent. The minimum recommended rate of 3 cfm per person, which is not much more difficult to attain than 1.5 cfm with forced ventilation, will maintain the carbon dioxide at about 0.5 percent and oxygen at about 19.5 percent. The capability of maintaining carbon dioxide at conservatively low levels, with correspondingly high levels of oxygen content, has several advantages.

1. A longer stay time is gained for continued occupancy after shut down of the ventilating system because of fire or for repair of disabled equipment.

2. Greater physical activity in the shelter becomes permissible.

3. Control of odors, and internally generated air contaminants will be more effective.

4. Conditions with respect to temperature, humidity, moisture, condensation, air distribution, and air motion may be improved.

5. Intermittent operation of a manual ventilating blower may be practicable.

INTERMITTENT BLOWER OPERATION

Manually operated or muscle-driven blowers, including the Ventilation Kits (VK), which have more than minimum capacity can be operated intermittently to maintain the chemical composition of the air. Intermittent operation, as opposed to continuous operation, is not only more convenient but also is more likely to be within the physical capacity of the shelter occupants. Possible operating schedules can be obtained from Figure 4.2, which is also reproduced from Reference 2.

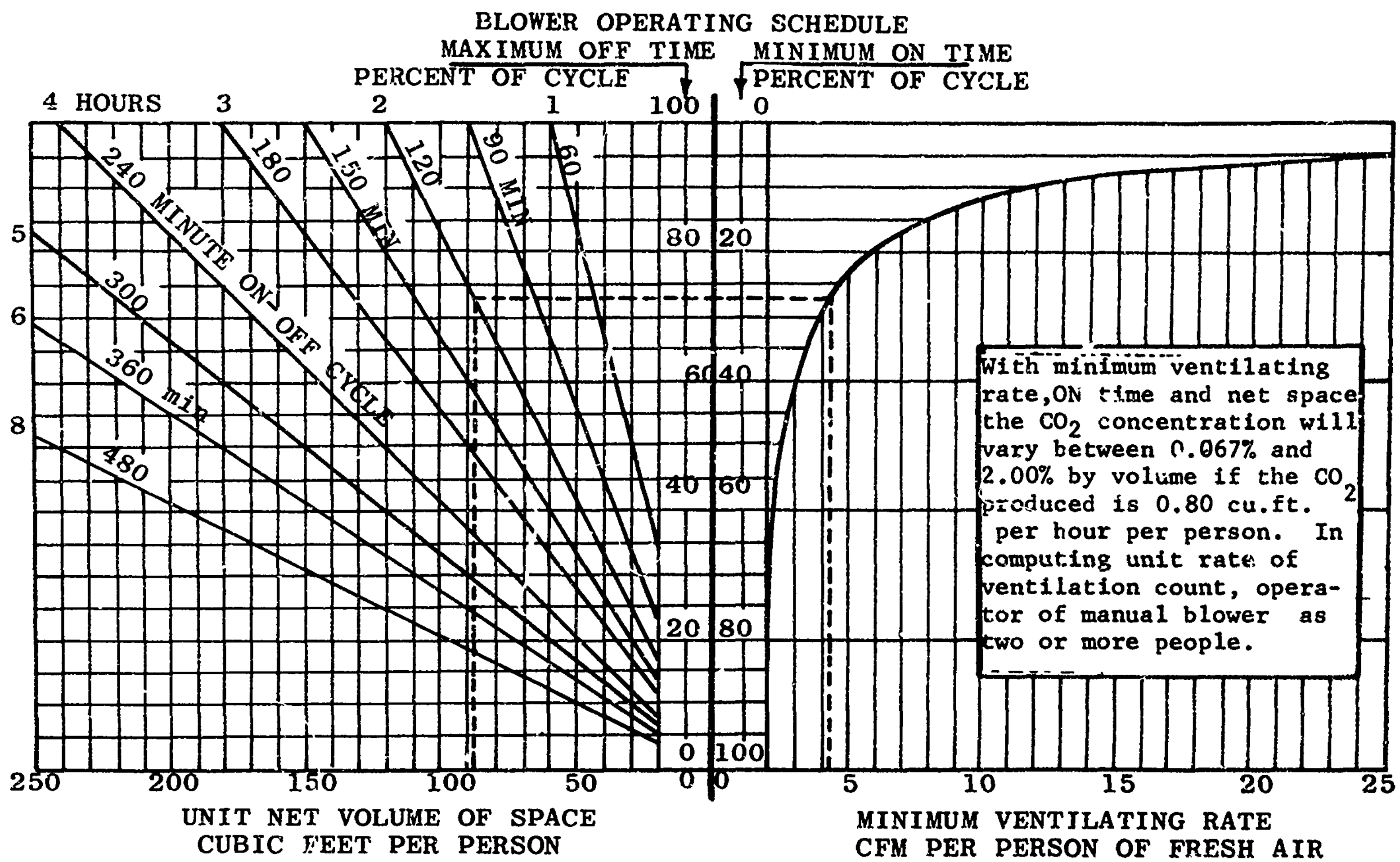
On this chart, the minimum ventilation rate, in cfm per person of fresh air, is equated to the minimum blower operating time expressed as a percentage of an ON-OFF cycle time, and the net free volume of shelter space, in cubic feet per person, is equated to the maximum blower shut down time expressed as a percentage of the same ON-OFF cycle time.

The chart is based on a carbon dioxide production rate of 0.80 cu ft/hr/person and a carbon dioxide concentration which varies during the cycle from 0.67 to 2.00 percent by volume.

In the example, show by dashed lines, it is known that the volume of shelter space is 88 cu ft/person. The blower may then be operated on a 2-hour ON-OFF cycle if the installed blower capacity is 4.3 cfm/person, with a minimum ON time of 27 percent or 32 minutes and a maximum OFF time of 73 percent or 88 minutes. If the installed ventilating rate is greater than 4.3 cfm/person or if the ON time is more than 27 percent, the maximum carbon dioxide concentration will be proportionately less than 2 percent.

CONTROL OF THE THERMAL ENVIRONMENT

The minimum recommended ventilation rate of 3 cfm per person is sufficient to control the chemical composition of the air within the specified limits of tolerance. However, in most locations in the United States the reliability of maintaining a tolerable thermal environment with this rate of ventilation



INTERMITTENT VENTILATION OF SHELTERS-REPITIVIE CYLCES FOR BLOWER OPERATION

FIGURE 4.2

is very low. Therefore, in most cases, the minimum ventilation rate required to meet the thermal environmental criteria will be greater than that required to control the chemical environment.

The governing factor, then, in determining required ventilation rates is the control of thermal environment. It is true that there may be times during cold weather when the necessity for maintaining the chemical composition of the air will require ventilation rates greater than are necessary for thermal control. However, the capacity of the ventilation system which must be provided for the shelter will be determined by the higher values of shelter temperature and humidity during hot weather.

The temperature and humidity that will develop in a shelter are determined by the heat and moisture balance at any time. The sources of heat which might be present are:

1. Heat losses of the occupants
2. Heat in the ventilation air
3. Heat from lights
4. Heat from mechanical equipment
5. Heat from chemical reactions in life support systems (not operating if ventilation system is operating)
6. Heat transfer to or from the surrounding earth or air
7. Heat from combustion processes such as open flames for cooking, lighting, or heating, or from absorption type refrigeration equipment

Sources of moisture in the shelter might include:

1. Moisture loss from occupants
2. Moisture in the ventilation air
3. Moisture from leaks in the structure
4. Evaporation from open containers of water, food or from sanitation systems

5. Moisture produced by life support systems (not operating if ventilation system is operating)
6. Moisture from combustion of hydrogen fuels used in cooling, lighting or refrigeration
7. Mositure from bathing and showers.

HEAT AND MOISTURE LOSSES BY OCCUPANTS

The heat losses by the body have been discussed in Chapter III. If thermal equilibrium of the body is assumed, the heat losses by convection, radiation, and evaporation must equal the metabolic rate. The average metabolic rate for sedentary persons is generally accepted to be about 400 Btu per hour (Btuh) per person. The proportion of this which is sensible heat depends on the dry-bulb temperature of the air. When the air temperature is equal to the skin temperature, heat transfer by convection and radiation becomes essentially zero, and the entire metabolic heat will be dissipated by evaporation. If the dry-bulb temperature of the air is greater than the skin temperature the heat transfer will be <u>to</u> the body. This heat, in addition to the metabolic heat, must be dissipated by evaporation if thermal equilibrium is to be maintained.

The partition of total heat loss into sensible heat and latent heat is given in Table 3.6 as is the pounds per hour of moisture evaporated.

HEAT AND MOISTURE IN VENTILATION AIR

The incoming ventilation air will bring with it heat and moisture. The total heat and the amount of water vapor are most easily determined from the psychrometric chart using the methods presented in Chapter II.

HEAT FROM LIGHTS

Since windows provide almost no attenuation of gamma radiation, the number and size of window areas in fallout shelters will be held to a minimum and the amount of natural light in the shelter may well be inadequate. The application of slanting techniques with the judicious use of roof overhangs, baffle walls and planters may result in shelter areas with large window areas

and sufficient natural light. Shelter areas on the mid floors of high-rise buildings may also have adequate window areas for natural light. However a source of artificial light will be necessary for nighttime operation of the shelter and in those areas of the shelter where daylight is inadequate. This light may come from candles, calcium carbide lamps, kerosene lanterns, gasoline lanterns, liquified petroleum gas (LP gas) lanterns, flashlights, battery-powered lighting units, incandescent lamps, or fluorescent lamps.

Candles, calcium carbide lamps and kerosene lanterns are readily available but provide very low levels of light. They are also open-flame combustion devices which consume oxygen and produce heat. Therefore they should be used only as emergency lighting.

Gasoline lanterns produce much more light than those previously mentioned but they are also combustion devices. In addition they require pressurization of a highly volatile fuel and create a serious fire hazard.

LP gas (propane) lanterns are also combustion devices which consume oxygen and produce heat. The fuel is highly volatile (propane vaporizes at $-40^{\circ}F$ at atmospheric pressure) but it may be piped in from a storage tank (or cylinder) which is located outside the shelter. The light produced is considerably greater than from a gasoline lantern, being exceeded only by incandescent and fluorescent lamps. A single propane lantern will consume about 0.32 cu ft of air per minute and will add 0.013 cu ft of water vapor and 0.04 cu ft of CO_2 per minute to the shelter environment. The heat output is about 2000 Btu per hour based on a fuel consumption of about 0.8 cu ft per hour. (14) Eight lanterns would be required to provide an average illumination level of two foot-candles in a 50-space shelter, which would mean 320 Btuh per occupant. This much heat probably could not be handled by the ventilation system. However, it is possible to enclose each lantern with a vented enclosure to exhaust most of the heat and the combustion products directly to the outside.

Although LP gas lighting systems are far from ideal and present many design problems, they do offer a

possible light source for shelters where no electric power is available. The fuel has a long storage life and the tanks have extremely good resistance to nuclear weapons effects (see Chapter VII).

Flashlights and battery-powered auxiliary lighting units are probably suitable for temporary or emergency lighting but battery life is short and the shelf-life of dry cell batteries is only about 1-2 years. They should not be depended upon as a primary light source.

The most desirable light sources for shelter use are incandescent and fluorescent lamps. These, of course, require a source of electric power and a wiring system in the shelter. They provide the greatest amount of light and create no unusual hazards. (Most people are aware of the normal electrical hazards.) All of the electrical energy input to the lights will be converted into heat. The amount of heat will be determined by the number and watt ratings of the lights in use (1 watt = 3.413 Btuh). A typical design level is 6 watts per person of incandescent lighting. In this respect, fluorescent lamps would have an advantage since they produce more light for a given power input. A 40-watt fluorescent tube will produce approximately the same amount of light as a 100-watt incandescent bulb. The initial cost of the fluorescent system, however, is greater than the incandescent and the wiring is somewhat more complicated.

HEAT FROM MECHANICAL EQUIPMENT

Mechanical equipment which might be located in the shelter includes auxiliary power generators, motor driven fans or blowers, heating or cooking appliances.

Auxiliary power generators should not be located in the shelter proper due to many factors, including the problem of heat dissipation. It may, therefore, be assumed at this point, that the ventilation of and heat dissipation from the compartment containing the power equipment is a separate problem.

If an electric motor is operating in the shelter the heat equivalent of the energy output is part of the heat load. The heat equivalent is:

$$Q = \frac{\text{Horsepower Rating}}{\text{Motor Efficiency}} \times 2544, \text{ Btuh} \quad \text{(Eq. 4.2)}$$

2544 Btuh is the equivalent of one horsepower.

The motor efficiency will vary with the size of the motor, being as low as 50 percent for 1/8 hp motors up to 80 percent for 1 hp motors and to about 88 percent for 10 hp and up. Obviously the heat input occurs only while the motor is running so an estimate must be made of the percentage of time the motor will be in use.

Strictly speaking part of the energy of the motor driving a fan or blower is converted into kinetic energy of the air. However, for shelter applications, the air movement in the shelter will probably be comparatively low so that the kinetic energy of the air will essentially be dissipated in turbulence. The effect will be the same as if all of the motor energy had been converted to heat.

If electric cooking appliances are used in the shelter the heat input will be equal to the power consumption, which is usually stated on the appliance, normally in watts. However, in this case, part of the heat will be sensible heat and part of it latent heat, due to moisture given off from the food during cooking. As a rule of thumb, about one-fourth of the heat may be taken as latent heat and the rest sensible.

If gas-burning cooking appliances are used, the proportion of latent heat will be about one-third, due to the moisture formed by the combustion of hydrogen in the fuel in addition to the moisture from the food.

The foregoing is based on the assumption that the cooking appliances will not be provided with an exhaust hood. Actually the nature of shelter living will preclude cooking to any great extent.

HEAT AND MOISTURE FROM LIFE SUPPORT SYSTEMS

The term "life support systems" could be applied very broadly to include any and all systems which support life. This would include all of the systems in the shelter and the shelter itself. However the term is used here in the limited sense as being the systems

for supplying oxygen and absorbing carbon dioxide during periods when fresh air is not available. Since such systems will not be in operation during the time the ventilation system is on, they are of no importance to the present discussion. They will be discussed, however, in Chapter X.

HEAT TRANSFER TO OR FROM THE SURROUNDINGS

If the earth surrounding an underground shelter is at a temperature lower than that of the shelter, heat will be transferred through the walls of the shelter to the earth. If the earth temperature is higher than the shelter temperature the transfer will be in the opposite direction, into the shelter. For above ground shelters the same heat transfer condition will occur between the shelter and the surrounding air.

Although these effects can be extremely important in the control of the thermal environment, the calculation of the heat transferred in this manner becomes more complicated than can be covered in this brief summary. For the moment it will be assumed that no heat is transferred in this manner, and the method of calculation will be deferred for discussion in the next chapter.

In some cases, in the design of underground shelters, the effect of heat transfer to the earth is ignored on the assumption (sometimes erroneous) that the earth temperature will be at or below shelter temperature and any transfer which does occur will be from the shelter to the earth. This will then be a bonus, or a safety factor, in the environmental control system.

HEAT AND MOISTURE FROM COMBUSTION PROCESSES

The heat and moisture gains from open-flame combustion processes have been discussed to some extent under the previous headings. In most cases open flames should be avoided in the shelter wherever possible, since they not only add heat and moisture but also consume oxygen and add carbon dioxide and, usually some carbon monoxide. They also are a fire hazard. If it is absolutely necessary that an open flame be used, every effort should be made to keep it outside the shelter proper (such as in a mechanical equipment room or in the entrance passage). If it must be in

the shelter, it should be separately vented, or at least located near the ventilation exhaust outlet so that the heat and products of combustion are carried out without mixing in the shelter air.

MOISTURE DUE TO LEAKS IN THE STRUCTURE

Water may leak into a structure for any of a number of reasons, unless it is carefully waterproofed during construction. During tests conducted by the University of Florida of 17 below-ground shelters in various parts of the country it was found that 12 showed a history of leakage (15). The extent of such leakage is almost impossible to determine in advance and the effect on the thermal environment will depend on conditions.

If the water, which collects on the floor or other surfaces, is evaporated due to heat transfer within the shelter it will raise the humidity but tend to lower the effective temperature. If, on the other hand, the water evaporates due to heat transfer from the outside, the effective temperature will be increased. A third possibility would be for the air next to the wetted surface to be at the same dew point as the water layer, in which case no evaporation would occur and the water layer would have no effect on the thermal environment.

EVAPORATION FROM OPEN CONTAINERS OF FOOD OR WATER

The rate of evaporation from containers of food and water will depend on the surface area exposed and on the difference in the saturated vapor pressure of moisture at the water (or food) temperature and the partial pressure of the water vapor in the air. Since food or water stored in the shelter will be at essentially the temperature of the shelter air, and since the relative humidity will probably be quite high, there should be very little pressure difference to cause evaporation. If reasonable care is used in keeping food and water covered (desirable also for hygienic reasons) the amount of moisture from this source should be very small. The heat of vaporization during evaporation would be absorbed from the surroundings, thereby tending to lower the dry-bulb temperature. However the humidity would increase.

MOISTURE DUE TO BATHING OR SHOWERS

The rate of evaporation during bathing activities depends also on the pressure difference between the saturated vapor pressure at water temperature and the partial pressure of the water vapor in the air. However, in this case, the wetted surfaces exposed are very large and, if hot water is used, the difference in pressures is enough to cause the evaporation of large amounts of water. Practically speaking, however, the problem involved here is largely academic, since few shelters will have a sufficient supply of water to permit any ablutions beyond face and hand washing. If, however, provision is to be made for such activities, the ventilation air should be exhausted through the bathing areas in order to carry away the water vapor produced and prevent its entering the living areas of the shelter.

COOLING BY VENTILATION

An analysis of the transient heat and moisture flows for any shelter can be performed if sufficient data are available. Such data would include:

1. Ambient temperature and humidity, wind velocity, latitude and cloud cover;
2. Ventilation rate;
3. Number of occupants and their metabolic rates;
4. Physical and thermal properties of the shelter, adjacent structures and surrounding soil;
5. Heat and moisture absorbed by mechanical cooling equipment, if any;
6. Heat and moisture dissipated by internal equipment;
7. If the shelter is in contact with the soil, the previous thermal history of the shelter and adjacent structures in order to determine the initial temperature distribution of the soil.

Analytical models have been developed which numerically treat the many aspects of this comprehensive analysis. Predictions based on these models closely approximate the results of simulated occupancy tests of shelters. However the amount of input data required and the complexity of the analysis require that the computations be carried out on an electronic computer.

Simplified models have been developed which permit computation by manual methods and also yield reasonably accurate predictions. These will be discussed in Chapter V. They also require a large amount of input data and the calculations can be very time-consuming.

These methods are useful for research purposes and for application to specific design cases but they are impractical for use where the ventilation requirements for a large number of shelters must be determined such as in the National Shelter Survey or in a community shelter plan program. In such cases the detailed input data is not readily available and the time requirements for computations become prohibitive.

A simplified method has been developed which is based on the fact that only a small percentage of the total metabolic heat generated in large shelters will be dissipated by heat transfer to the shelter walls during hot summer weather. This would be essentially true for above-ground shelters in the core areas of large buildings and in most below-ground shelters after the first week of occupancy. The method neglects any heat loss or gain through the walls, floor and ceiling of the shelter and requires that all heat and moisture be removed by the ventilation air. Thus the shelter is treated as an adiabatic system and the need for detailed information about thermal characteristics of the shelter and its surroundings is eliminated.

The results of this method can be shown in the simple form of the chart in Figure 4.3. The chart is based on the metabolic heat load of sedentary people and does not include any other heat loads.

In order to use Figure 4.3 to determine the minimum required ventilation rate it is necessary to know the

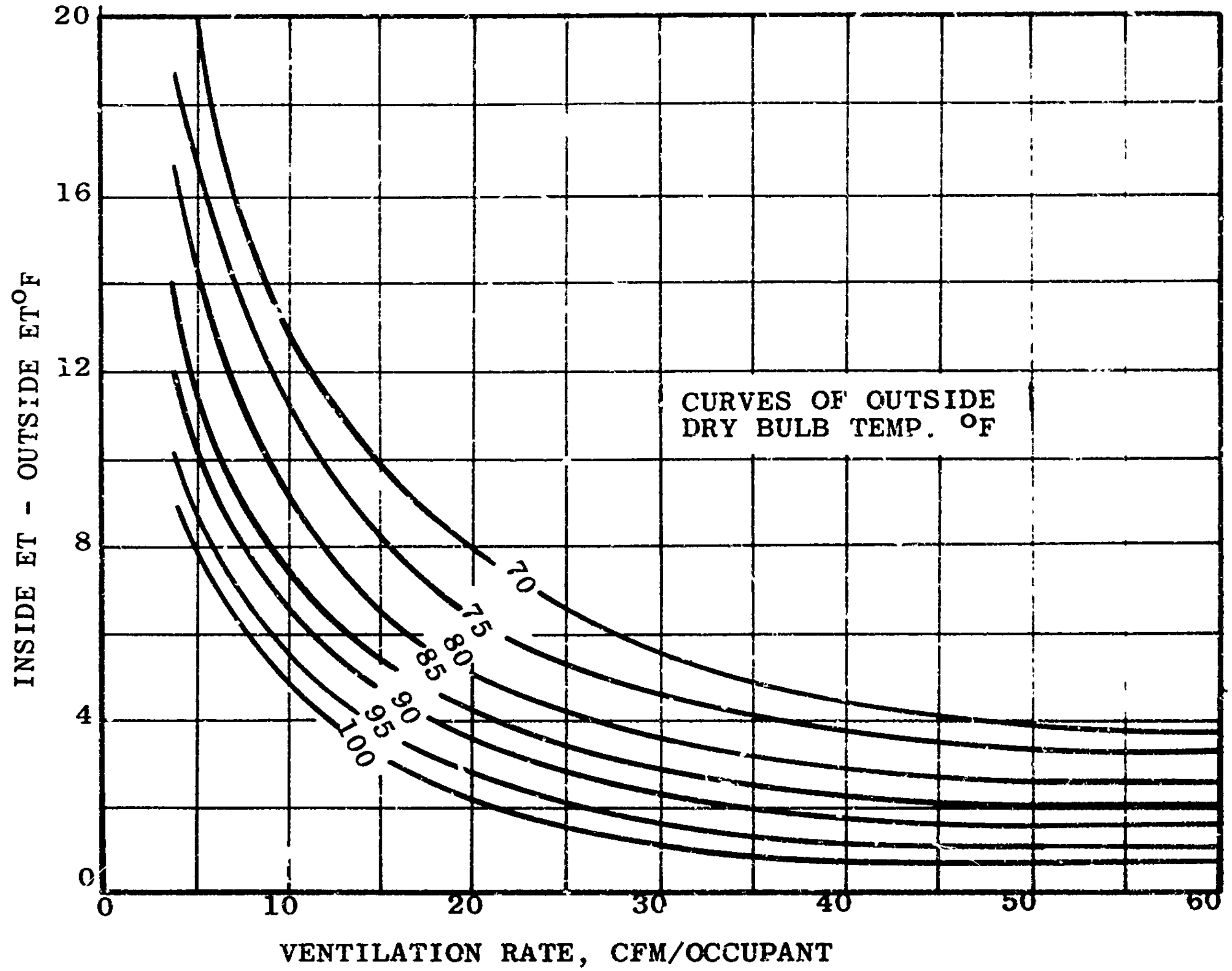


Figure 4.3 Effective Temperature Relations Simplified Model (Unadjusted)

daily average dry-bulb temperature and the daily average effective temperature of the outside air for a particular day. Then select a limiting shelter effective temperature, say 82° FET. The daily average outside effective temperature for the day in question is subtracted from the shelter effective temperature. (If the result is negative, the limiting shelter ET cannot be met by ventilation with outside air.)

Find the difference in effective temperature on the ordinate of the chart and move horizontally to the curve representing the daily average outside dry-bulb temperature. Move vertically to the abscissa to read the required ventilation rate in cfm per occupant.

The chart can be used also to predict the average shelter effective temperature for a given ventilation rate. In this case, the chart is entered from the value of the ventilation rate on the abscissa. Then move vertically to the curve for the daily average dry-bulb temperature and then horizontally to the ordinate to read the effective temperature difference. This, added to daily average outside effective temperature gives the predicted daily average shelter effective temperature.

Note that the method is based on daily average temperatures and results in a daily average shelter effective temperature. The results of a large number of simulated occupancy tests indicate that the shelter effective temperatures do not vary more than plus or minus 2° from the average during any one day. It is probable that these small variations from the average would have very little effect on the physiological response of the occupants, either by increasing the heat stress during the hotter parts of the day or by providing a respite during the cooler period. It is, therefore, considered valid to use the daily average of effective temperature as the measure of shelter environment.

Based on the results of simulated occupancy tests, the simplified method, using 24-hour average inlet conditions, usually overestimates the 24-hour average shelter conditions in basement and below-ground locations, even near the end of a two-week occupancy period. The estimate of average shelter effective temperature exceeds that obtained by test by a degree or more even in the final phases of the test and exceeds it by several degrees during the first few days of the test. The apparent reason for this overestimation is that most below-ground

shelters are not truly adiabatic and there is some heat transferred through the walls of the shelter to the surrounding earth. During the occupancy period the earth temperature will increase, due to the heat transferred to it, and therefore, the amount of heat transferred in the later stages of occupancy will be decreased. Thus the shelter will approach the adiabatic condition after about 10 days and the simplified method of analysis more closely approximates actual conditions.

The simplified method can be used in conjunction with the weather history of any location to determine the expected number of days that a given ventilation rate will produce a given shelter effective temperature or less. The ratio of this number of days per year to 365 is the reliability of the ventilation capacity. The procedure would be:

1. Determine the hourly coincident dry-bulb and wet-bulb temperatures for each day from the weather history and average these over the day;

2. Tabulate the number of days that have the same set of coincident daily average temperatures;

3. Determine the ventilation rate required for each of the sets of coincident daily average temperatures to produce a given daily average shelter effective temperature;

4. Tabulate the number of days for which a given ventilation rate produces a given daily average effective temperature or less;

5. Determine the ratio of this number to the total number of days in the weather history available.

It is probable that there are at least ten years of weather data available for most localities. It can be assumed that the ratio as determined above, based on these data, would be valid for any future year.

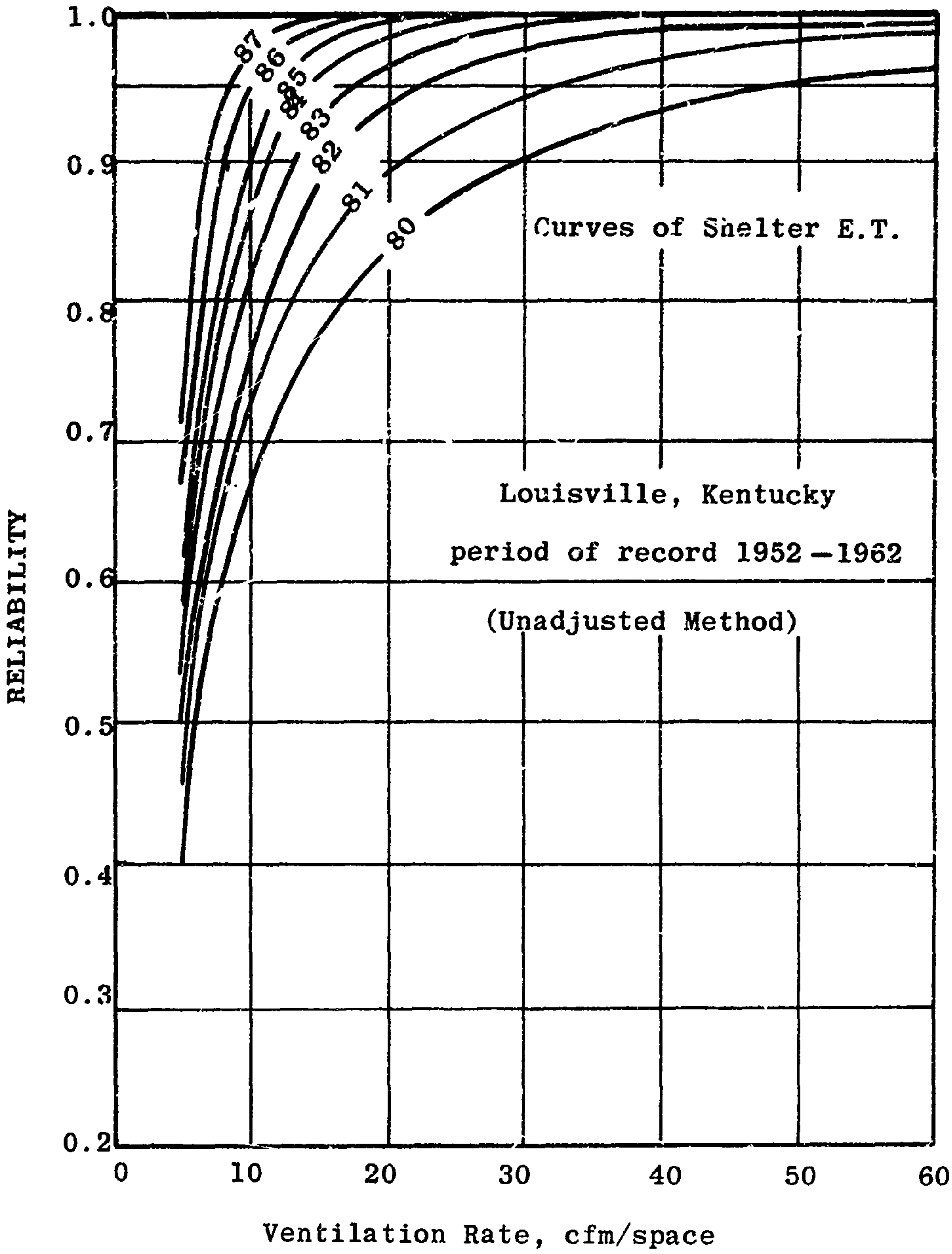


FIGURE 4.4 RELIABILITY OF NOT EXCEEDING STATED EFFECTIVE TEMPERATURE

Analyses of this type have been made for 91 weather stations in the United States and curves, similar to Figure 4.4, have been developed for these stations. The chart in Figure 4.4 is for Louisville, Kentucky based on weather data from 1952 to 1962. From this chart the required ventilation rate may be read for any given limiting effective temperature and any desired reliability.

From this chart the ventilation rate to give a 90% reliability of not exceeding 82°FET is read at approximately 16 cfm per person. It can be seen that this same ventilation rate would give a reliability of not exceeding 85°FET of about 98%. The reliability of not exceeding 80°FET is only about 79% at this rate of ventilation. It is apparent from these curves that at the higher values of reliability large increases in the ventilation rate are required to attain lower values of limiting effective temperature. At the same time, to attain higher reliability at a given shelter effective temperature also would require a large increase in ventilation rate. Although these facts are generally true for all cities for which the curves have been developed, the rates at which the parameters vary are significantly different. For cities in the northern portions of the United States a given rate of ventilation will produce a reliability of not exceeding 82°FET only slightly less than the reliability of not exceeding 85°FET. In the southern part, especially in the gulf coast states, this would not be true. Here a given ventilation rate may result in a high reliability of not exceeding 85°FET but the same ventilation rate would produce a relatively low reliability of not exceeding 82°FET.

When the shelter conditions as predicted by the simplified method were compared with the results of simulated occupancy tests of basement and below ground shelter locations, it was found that the simplified method overestimated the shelter ET by about one degree. Based on this and other considerations, the procedure was adjusted to reduce the predicted ET by one degree. Thus the reliability curves of the type shown in Figure 4.5 were reduced one degree, the 83 degree curve becoming a 82 degree curve, the 82 degree becoming the 81 degree curve, and so on.

The data from simulated occupancy tests suggest that the actual environment in shelters would be spread

about this adjusted estimate, with about two-thirds of all cases being within one degree of the estimate. Less than 20% of all cases would be underestimated by more than one degree.

The charts from the 91 weather stations were used to plot contour lines of equal ventilation rates over the country as shown in Figure 4.6. In order to protect the small fraction of shelters for which the environment might be underestimated by a wide margin, and to further simplify the procedure, the areas between contour lines were regarded as zones of equal ventilation rate with the rate for the entire zone being that of the highest-value contour bounding the zone. For example, the entire area between the 15 cfm contour and the 20 cfm contour is taken as requiring a ventilation rate of 20 cfm per person. In this way only those shelters near the high boundary would not be given excess ventilation.

It is considered that the number of shelters for which the system would underestimate the ventilation rate and which, in addition, would be close to the high boundary of the zone, would be quite small. Furthermore, the occupants of such shelters would have the alternative of moving into areas of the building peripheral to the shelter area or even to another shelter if the thermal environment became intolerable. This alternative would not be available if radiation levels were high enough to prohibit moving into areas with a lower protection factor. Thus, the lives of the occupants would be endangered only when this combination of unrelated circumstances existed.

To use the map of Figure 4.5, it is necessary only to determine the number of occupants of a shelter and multiply by this by the ventilation rate read from the map in order to determine the required total ventilation capacity for the shelter.

It will be recalled that the method is based on the heat load of sedentary people (400 Btuh per person) with no other heat loads considered. If other heat loads are present in the shelter it is suggested that they be treated as additional occupants at the rate of one additional occupant per each 400 Btuh of additional heat load.

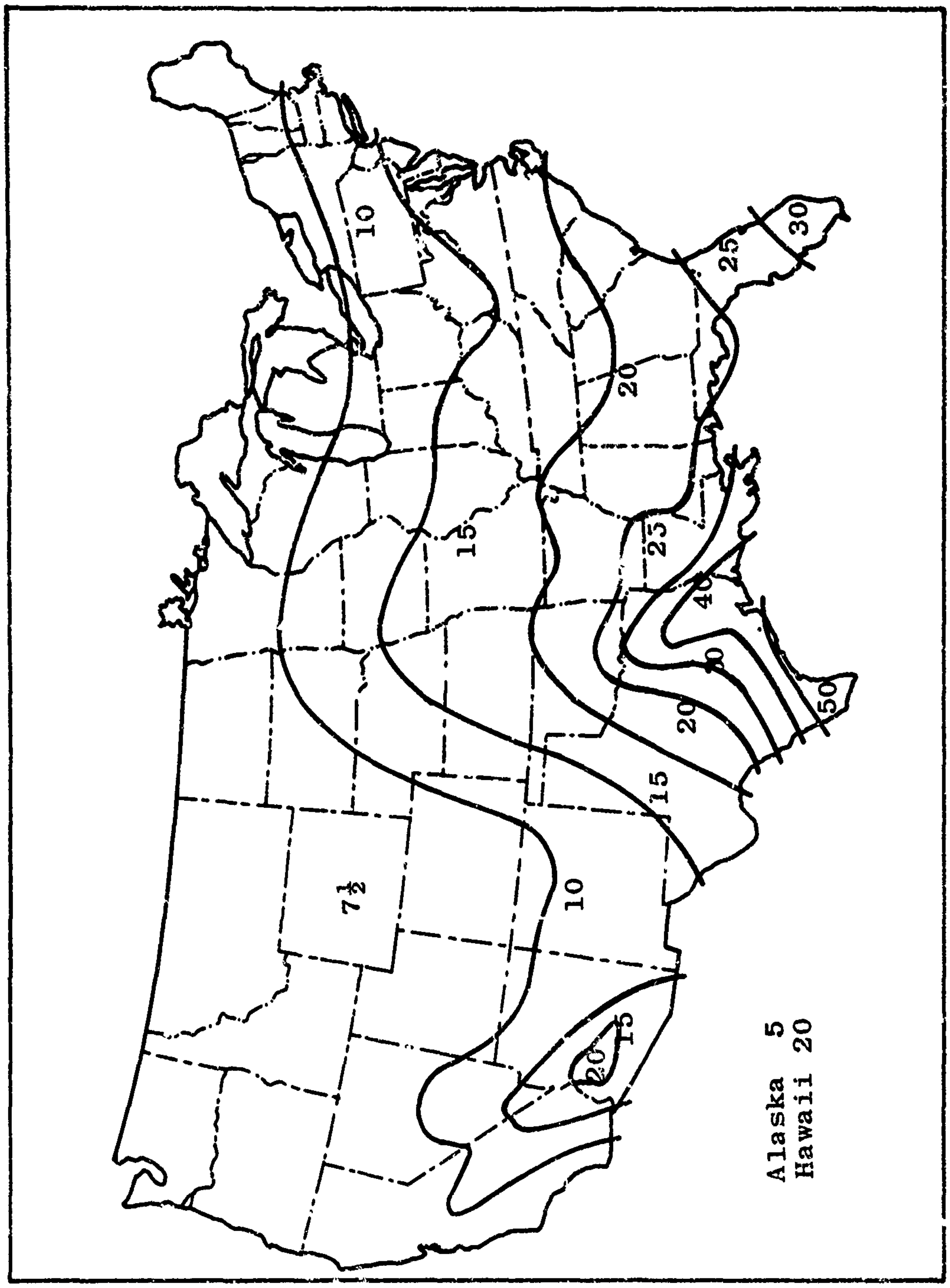


FIGURE 4.5

ZONES OF EQUAL VENTILATION RATES IN CFM PER PERSON

VENTILATION KIT

The simplified method of determining a ventilation rate was developed by the Office of Civil Defense principally as a means of establishing the criteria for the distribution of ventilation kits (VKs) to identified and stocked shelters. The National Shelter Survey has located many shelter areas in existing buildings which cannot be used or in which the capacity must be reduced because of inadequate ventilation. Most of these areas are in basements or other below-ground locations where natural ventilation is unlikely to provide a habitable environment.

Above-ground spaces are not considered for ventilation improvement in this program since natural ventilation may be capable of maintaining habitable environments in nearly all such areas. However, it appears probable that there could be a need for additional ventilation capability in above-ground areas in the regions of high ventilation rate, especially in the Gulf Coast states.

The Ventilation Kit is a complete mechanical ventilating system which is portable and can be assembled and operated by untrained persons. It can be driven either electrically or by human muscle power by means of a bicycle-type drive unit. There are two types: either one or two pedal drive. The number and type of VKs stocked in a shelter will be determined by the total ventilation capacity required.

The basic components of the VK are a 20-inch propeller-type fan with stand and shroud, a drive module with stand, pedals, drive chain, saddle seat(s) and handlebar, two rolls of 20-inch diameter, 4-mil plastic duct (one 130-foot roll and one 90-foot roll), two plastic duct elbows, and accessories such as duct adaptor, tape, electric plugs, scissors, wrench, screwdriver and lubricant. The VK comes sealed in two cartons, one containing the fan assembly and the other the drive module.

The fan is arranged for use with ducting on the discharge side so that the VK is used to exhaust hot, humid air from the shelter. Thus, it would be placed as far as possible from the air inlet doors and windows in order to obtain maximum air distribution. It should be placed so that the plastic duct is as short and as

straight as possible in order to minimize friction losses in the duct.

The plastic duct should be completely laid out before taping to the fan shroud. The duct adaptor is used to assist in sealing around the discharge duct where it passes through a sealed doorway. Pieces of surplus duct are cut for use in sealing openings which might cause short circuiting of air to the fan.

The capacities of the one-man and two-man VK units are shown in Table 4.1.

TABLE 4.1

CAPACITIES OF VK UNITS, CFM

Equivalent Duct Length, feet	One-Man Unit	Two-Man Unit	Motor Drive
100	2400	3000	2900
200	2100	2800	2690
300	1900	2500	2520
400	1700	2250	2370
500	1550	2000	2230
600	1450	1900	2110
800	1300	1700	1930
1000	1250	1650	1790

The capacities for pedal-driven operation are based on a human muscular power output of 0.1 horsepower per person. The fan motor furnished with the VK is a 1/3 horsepower, 115 volt, single phase, permanent-split capacitor motor. The motor efficiency is about 60 percent so the output is about 0.2 horsepower, the approximate equivalent of the two-person pedal drive.

A table can be made showing the capacities of various numbers and combinations of one-man and two-man VK units for the various equivalent duct lengths. The per capita ventilation requirement from the zonal map is used together with the number of shelter occupants, the equivalent length of ducting, and the rated

capacity of the VK units to determine the number and type of units required. Both the equivalent length of ducting and the total ventilation requirement are rounded off to the nearest tabular entry. Thus a shelter for 150 persons in a zone where the per capita ventilation rate is 15 cfm would have a total ventilation requirement of 2250 cfm. If the estimated equivalent duct length is 175 feet it would be rounded to 200 feet. The nearest tabular entry would be a single one-man unit with a capacity of 2100 cfm. This appears to be less than the required amount. However the equivalent duct length was actually less than 200 feet so that slightly more than 2100 cfm could be expected. Also the zonal map overestimated the required ventilation requirement except for locations near the high border.

There exists the possibility that the equivalent duct length would be rounded downward giving a tabular value less than the amount of ventilation required. If this location were also close to the high border of the zone there is a possibility that a deficit in ventilation would result. The number of shelters where both conditions would exist is probably very small.

NATURAL VENTILATION

It was mentioned that the VK program is planned principally for basement and other below-grade shelter areas since above-ground shelters can probably maintain a habitable environment by means of natural ventilation. This means that the ventilation can be planned to take advantage of the building configuration, openings, outside winds and circulation paths.

Natural ventilation would be most applicable to shelter areas in existing buildings which have large openings and passages necessary to move large quantities of air with small pressure differentials. In high-rise buildings windows could be opened at the top floors and near ground level to provide a chimney effect for ventilation of shelter areas on the mid-floors. If the shelter areas are located in the inner parts of large buildings with interior partitions the windows at the shelter level can be opened to permit a crossflow of air. If the windows are open during the time fallout is being deposited there may be some infiltration but the amount probably would be very small and not reduce the protection factor of the shelter area to any great extent.

On the other hand, if the shelter area is on higher floors and has no interior partition, it would probably be best to keep the windows closed during the time fallout is being deposited to prevent possible infiltration. Once the particles have ceased to fall, it would be safe to open the windows. Since window glass provides almost no attenuation of gamma radiation, whether the windows are open or closed has no appreciable effect on the protection factor. On the mid-floors of high-rise buildings, there would be no danger of fallout particles on the ground infiltrating through the open windows. Therefore, the windows could be opened as necessary to provide ventilation.

As a general rule it can be said that the amount of air flow depends upon the size of the exhaust opening and the direction of the air flow depends upon the inlet opening. It would thus be desirable to have as many and as large openings as possible on the lee side of the building in order to provide the maximum volume of flow. On the windward side windows would be opened or closed as necessary to provide the best directional effect of the flow of air. It would also probably be advantageous to open windows on the lee side floors above the shelter area in order to draw the hot air upward. Obviously stairwells and other vertical passages would have to open to permit the movement of air.

These same principles would also apply in the use of the VK units. Here the VK provides for the volume and direction of the exhaust. The air inlet openings would then be provided to create the required direction of flow through the shelter. All other openings would be sealed off to prevent short circuits in the air flow pattern.

AIR DISTRIBUTION IN SHELTER

It has been found that a series flow of air through the shelter is more beneficial than parallel flow. In other words, all of the air should enter at one end of the shelter and exhaust at the opposite end. In this manner each person receives the full flow in series. Obviously, there will be a variation in conditions through the shelter with the lowest effective temperature near the inlet and the highest near the exhaust. However, both theoretical calculations and experimental evidence show that only at the locations near the

exhaust will the effective temperature be as high as it would be in the entire shelter with parallel flow. (26)

If the shelter area is too wide to make effective use of the series flow arrangement, it would be desirable to erect partitions to act as baffles to direct the flow in a serpentine path through the space. This will create the necessary series path. However, care must be taken to insure that dead air spaces are not created.

There are several advantages to the use of the series flow of ventilation in addition to the fact that the average effective temperature of the shelter will be lower. The principal one is the fact that the shelter manager will have some flexibility in handling the distribution of the occupants. Those with a lower tolerance to heat stress can be placed near the ventilation inlet where conditions should be most favorable.

In most shelters there will probably be some variation in protection factor in the various areas. The shelter manager will probably wish to rotate the occupants to the areas in order to equalize as much as possible the total radiation dose received. If there are also variations in effective temperature, he can use the same technique to equalize the exposure to heat stress.

As was pointed out earlier, people can tolerate a high effective temperature better if they can get a restful night's sleep. Thus, it may be desirable to locate the sleeping sections of the shelter near the ventilation inlet since the conditions there would be more favorable for restful sleep. This would be especially advantageous if sleeping must be done in shifts. In this case the lower metabolic rate of sleeping persons (about 240 Btuh) would cause a smaller increase in effective temperature of the inlet air. The air reaching those who were awake would then provide somewhat more cooling effect than it would if the people near the inlet were awake and more active.

PRACTICE PROBLEMS

4.1 It is required that the CO_2 concentration in a shelter be held below 6% for 6 hours of "buttoned-up" operation. What must be the volume of shelter space per person? What would be the oxygen concentration?

4.2 If the shelter in Problem 4.1 must be capable of 24-hour "buttoned-up" operation, what must be the volume of space per person?

4.3 A shelter has a volume of 75 ct ft/person. How long can it be operated without ventilation if the CO_2 is not to exceed 2%? If the CO_2 is allowed to go to 4%, how long can the shelter be operated without ventilation?

4.4 A shelter is 25' x 40' x 8' and is designed for 100 persons. It is estimated that 100 cfm of fresh air are available by natural ventilation. How long would it take for the CO_2 concentration to reach 1.0%?

4.5 In the shelter in Problem 4.4 how many persons could be sheltered if the CO_2 is not to exceed 1.0% in 24 hours?

4.6 A shelter in Boston, Massachusetts, has a capacity of 300 persons. What total ventilation rate is required if shelter is to have a 90 percent reliability of not exceeding 82° FET?

4.7 How many one-man and/or two-man PVK units would be necessary to meet the ventilation requirement of the shelter in Problem 4.6 if the estimated equivalent length of duct is 475 feet?

4.8 A 500-occupant shelter is located in New Orleans, Louisiana. How many PVK units would be required to meet the ventilation requirements of this shelter? The estimated equivalent duct length is 530 feet.

4.9 A shelter for 150 people in St. Louis, Mo., can be equipped with PVK units so that the equivalent duct length is 150 feet. One 2-man unit is supplied for the shelter. Will this provide adequate ventilation?

CHAPTER V

HEAT TRANSFER THROUGH SHELTER BOUNDARIES

The analysis of ventilation rates required to maintain a tolerable thermal environment, as presented in the previous chapter, was based on the metabolic heat of sedentary persons with no other heat loads considered and treated the shelter as an adiabatic system. However, the actual conditions in a shelter are not this simple and will have a modifying effect on the required ventilation rates. The simplified method of Chapter IV is adequate for use in analyzing large numbers of shelters in order to determine the basis for deployment of VK units or for similar programs, but for shelter design purposes a more sophisticated approach would be desirable.

It was pointed out that there could be some shelters wherein the ventilation would be inadequate when determined by use of the zonal map of Figure 4.5, although the number of such shelters would be small. The number of shelters at risk is considered to be acceptable in view of the advantages of the simplified method. In shelter design, however, there is only the one shelter to be considered and the possibility of inadequate ventilation of that shelter by use of the simplified method is not an acceptable risk. The time, effort and professional judgment required to make a more accurate estimation of the needs for that shelter are justified. However, it should be remembered that even individually designed shelters involve some degree of risk since it would be extremely expensive to build a shelter which had 100 percent reliability.

In tests of a 100-man underground shelter, using both human and simulated occupants, the U. S. Naval Radiological Defense Laboratory (USNRDL) found that approximately 69 percent of the total heat loss from the shelter was lost in the ventilating air for both the human occupancy test and the simulated occupancy test. The remaining 31 percent was transferred to the surrounding earth (16). These values would vary for other types and sizes of shelters.

Extensive tests, using simulated occupants, conducted by the University of Florida over a period of about two years in various parts of the United States, have revealed that tolerable conditions can be maintained

most of the time by ventilation alone. The tests were conducted under the former criterion of 85° FET as the tolerable limit. Under severe conditions the shelter effective temperature may exceed even this limit but this will occur during the hottest part of the diurnal temperature cycle and last for a short period of time only before dropping back to more acceptable levels as the atmospheric temperature decreases. This, in general, is due to the favorable influence of heat conduction to the earth surrounding the shelter. In only one case was it not possible to maintain conditions below the 85° FET criterion then in use and this occurred at a location and time when the air temperature and humidity were both high and, in addition, the ground temperature was exceptionally high. This particular shelter was located below-ground in the downtown section of a large city in an area indicated in Figure 4.5 as requiring a ventilation rate of 50 cfm per person.

In analyzing the shelter thermal system the following factors would be considered as affecting, or being affected by, the physical environment. Some of these have already been discussed in previous chapters.

1. The size and shape of the shelter with respect to surface area, volume, geometry and exposure;

2. The number of occupants;

3. The duration of occupancy;

4. The metabolic characteristics of the occupants in relation to energy expenditure, sensible and latent heat losses, oxygen consumption, and carbon dioxide production;

5. The physiological and psychological reactions of the people to the immediate situation;

6. Clothing (insulating properties, absorptivity);

7. Diet (solid and liquid, including drinking water);

8. The temperature, humidity and air motion in the shelter space (Effective Temperature):

9. Interior surface temperatures and moisture condensation;

10. Temperature and humidity of air leaving the shelter;

11. Interior heat and moisture sources other than people;

12. Heat flow from adjacent structures or heat sources;

13. Thermal properties of the shelter and surrounding materials (conductivity, density, specific heat, diffusivity, moisture content);

14. Thickness and thermal properties of cover and shielding materials;

15. Weather conditions with respect to variable temperature, humidity, solar radiation, wind and precipitation;

16. Initial conditions of the shelter environment and its surroundings (temperature distribution, moisture);

17. Temperature and humidity of fresh air or air supplied to shelter space;

18. Rate and method of ventilation with fresh and recirculated air (cooling, heating, air conditioning);

19. Required degree of reliability.

If it is assumed that the mechanical engineer will not be responsible for the design of the shelter structure, but will design the mechanical systems only, several of the preceding parameters are beyond his control. They may, however, have been determined and, for design purposes, will be essentially fixed. This would include such factors as the size and shape of the structure, the number of occupants, the shelter materials, the shelter site and the surrounding materials and structures. It is, of course, possible that the structural engineer or architect will be able to modify some of these factors if the thermal analysis makes it necessary or advisable.

The duration of occupancy will be determined by the duration of the threat. In the case of a fallout shelter, the occupants must remain in the shelter until the intensity of radiation outside has decreased to a safe level. For design purposes, fallout shelters are normally analyzed on the basis of a 14-day occupancy. The factors affecting the stay-time required cannot be evaluated in advance, so the 14-day period is a reasonable compromise.

The metabolic characteristics of people cannot be changed by the design engineer other than by the effect of environmental conditions on the sensible and latent heat losses. However, reasonable average values have been established and can be used for design purposes. During shelter occupancy, however, the shelter management can control metabolic heat, to some extent, by limiting activities.

The physiological limits of tolerance are beyond the control of the designer but have been reasonably well established to the point where criteria for design limitations are more or less fixed. The psychological limitations are, as yet, not defined nor are the factors affecting these limits clearly understood. Here the designer is faced with using the small amount of information available and trying to exercise the best judgment possible, and then hoping for the best.

The variations of atmospheric temperature, humidity, solar radiation, wind and precipitation are beyond the control of the designer. Consequently, there is no control over the condition of the supply air for ventilation. If data are available from Weather Bureau records to establish reasonable average values of coincident dry-bulb and wet-bulb readings, these may be used for design purposes. Lacking these data, or other reliable information on the local weather history, data for design purposes can be obtained from Table 5.1 which gives design dry-bulb and wet-bulb temperatures for selected cities in the United States. These data have been abstracted from Table 1, Chapter 26, 1963 ASHRAE Guide and Data Book, which gives data on the highest 1, 2½, and 5 percent of all the hours (2938) of the months of June through September.

The 5 percent data means that, in a normal summer, temperatures will be at or above those given in the Table only 5 percent of the time, or for about 150 hours. These hours would not, of course, occur consecutively but would occur two or three hours at a time during the hottest part of the diurnal cycle.

It should be emphasized that the data from this table should be used only when more accurate information is not available. The dry-bulb and wet-bulb temperatures given in the table are not coincident readings but are the maximum readings. Normally the maximum wet-bulb temperature would not coincide with the maximum dry-bulb temperature so that the table indicates humidities somewhat higher than would actually exist. The Office of Civil Defense has coincident weather data for the cities indicated by an asterisk in Table 5.1.

TABLE 5.1

SUMMER CLIMATIC CONDITIONS

Station		5% Design Dry Bulb	5% Design Wet Bulb	Outdoor Daily Temp. Range
Ala.,	Birmingham	93	77	21*
Alaska,	Fairbanks	75	62	19
Ariz.,	Flagstaff	80	60	28
	Tucson	100	71	26*
Ark.,	Little Rock	94	78	22*
Calif.,	Los Angeles	86	70	22*
	San Francisco	79	62	21*
Colo.,	Denver	88	63	29*
Conn.,	Hartford	86	74	24
D. C.,	Washington	90	76	18*
Fla.,	Miami	89	79	10*
	Orlando	89	79	19
	Tallahassee	91	79	20*
Ga.,	Atlanta	91	76	20*
	Savannah	92	79	18*
Hawaii,	Honolulu	84	73	9*
Idaho,	Boise	91	65	31*
Ill.,	Chicago	89	76	21*
Ind.,	Indianapolis	89	76	22
Iowa,	Des Moines	89	76	21*

TABLE 5.1
(Continued)

	Station	5% Design Dry Bulb	5% Design Wet Bulb	Outdoor Daily Temp. Range
Kansas,	Wichita	96	75	23*
Ken.,	Lexington	90	76	21
La.,	New Orleans	91	79	14*
	Shreveport	95	79	21*
Maine,	Augusta	83	71	22
Mass.,	Boston	86	73	16*
Mich.,	Detroit	86	74	21*
	Sault Ste. Marie	78	69	23
Minn.,	Duluth	79	69	20*
	Minneapolis	87	74	22*
Miss.,	Jackson	94	78	23*
Mo.,	Kansas City	94	76	21*
	St. Louis	93	77	18*
Mont.,	Butte	80	57	35
Nebr.,	North Platte	90	72	27*
	Omaha	91	76	22*
Nev.,	Las Vegas	106	70	30*
	Reno	89	61	45*
N. Mex.,	Albuquerque	91	63	25*
N. Y.	Albany	85	73	22*
	New York(La Guardia)	87	75	16*
	Rochester	85	72	23
N. C.,	Raleigh	91	77	21
N. D.,	Bismarck	87	71	27*
	Fargo	85	72	26
Ohio,	Cleveland	87	74	22*
	Columbus	88	75	26*
Okla.,	Oklahoma City	95	76	21*
Ore.,	Portland	81	66	21*
Pa.,	Philadelphia	88	76	21*
	Pittsburgh	85	73	21*
S. C.,	Columbia	93	78	21*
S. D.,	Rapid City	88	69	27*
Tenn.,	Knoxville	90	76	22*
	Memphis	94	79	20*
Texas,	Amarillo	92	70	28*
	Fort Worth	99	76	20
	Houston	92	79	17*
	San Antonio	96	76	23*
Utah,	Salt Lake City	91	64	32*

TABLE 5.1
(Continued)

	Station	5% Design Dry Bulb	5% Design Wet Bulb	Outdoor Daily Temp. Range
Vt.,	Burlington	83	72	24*
Va.,	Richmond	92	77	21
Wash.,	Seattle-Tacoma	77	63	22*
	Spokane	85	63	26*
W. Va.,	Charleston	88	75	24
Wis.,	Milwaukee	84	73	20*
Wyo.,	Casper	87	61	31

Thus the mechanical designer will be able to control only the rate and method of ventilation and the distribution of air within the shelter. To a certain extent, he can also control internal heat and moisture sources. By controlling these factors he can, in turn, control the temperature, humidity and air motion within the shelter, and, within limits, shelter surface temperatures and moisture condensation.

The dissipation of heat from the shelter to the surrounding earth is of great importance in the control of the thermal conditions in an underground shelter. In general it would be expected that earth temperatures would be less than shelter temperatures during times of greatest heat stress and that heat would be transferred through the walls of the shelter to the earth. Under other conditions shelter temperatures may be below the earth temperatures and heat will flow from the earth into the shelter. It is necessary, therefore, to have some information concerning the properties of the earth surrounding the shelter.

The properties of interest in heat transfer calculations are the thermal conductivity and the thermal diffusivity. These are affected by type of soil, the density, the moisture content and the specific heat.

The thermal conductivity (k) is a property of a material which determines the rate at which heat will flow through it when there is a difference in temperature

between the two sides of the material. It has dimensions of:

$$k = \frac{Btu}{hr - ft^2 - deg\ F/ft} \quad \text{or} \quad \frac{Btu - ft}{hr - ft^2 - deg\ F}$$

In other words, k indicated the amount of heat, in Btuh, which will flow through one square foot of surface for each foot of thickness, for each degree of temperature difference between the two sides of the material. In some cases values of conductivity for building materials are given on the basis of an inch of thickness, rather than a foot, so that:

$$k = \frac{Btu - in}{hr - ft^2 - deg\ F}$$

These values would be divided by 12 in/ft to obtain values based on one foot of thickness.

The heat which is transferred through a material then can be determined by:

$$q = \frac{k\ A\ (t_1 - t_2)}{x} \qquad \text{(Eq. 5.1)}$$

Where:

q = heat transferred, Btuh

k = thermal conductivity as defined above

A = Area through which heat flows, sq ft

$t_1 - t_2$ = temperature difference between the two surfaces, °F

x = thickness of the material, ft

The flow of heat will be in the direction of the lower of the two temperatures.

This equation assumes that the decrease in temperature is constant for each increment of thickness, an assumption which is not necessarily true. However it should be sufficiently accurate for purposes of this discussion.

The thermal diffusivity (α) is a property of the material which is defined by:

$$\alpha = \frac{k}{\rho c_p} \quad \frac{\left[\dfrac{\text{Btu - ft}}{\text{hr - ft}^2 \text{ - deg F}}\right]}{\left[\dfrac{\text{lb}}{\text{ft}^3}\right]\left[\dfrac{\text{Btu}}{\text{lb deg F}}\right]} = \frac{\text{ft}^2}{\text{hr}}$$

Where:

α = thermal diffusivity, ft^2/hr

k = thermal conductivity Btu/hr - ft^2 - deg F per ft

ρ = density, lb/ft^3

c_p = specific heat at constant pressure, Btu/lb - deg F

The diffusivity might be considered as the ratio of the ability of the material to conduct heat divided by its ability to store heat.

It is apparent that it is desirable to have information concerning the density and specific heat of the soil in order to determine the diffusivity from the conductivity. The diffusivity can, however, be estimated from Figure 5.1, which has been reproduced from Reference 17. It can be seen that values of diffusivity range from about 0.005 to about 0.045 but the most values fall in the range of 0.015 - 0.025.

The thermal conductivity of soils may be estimated from Figure 5.2, which also has been reproduced from Reference 17. Notice that both the conductivity and the diffusivity increase with increased moisture content. Thermal diffusivity of a particular soil increases with the moisture content up to a maximum, after which the increase in thermal conductivity is overcome by increases in density.

Values of thermal conductivity, specific gravity and specific heat for several common materials are listed in Table 5.2. The values are taken from the 1963

ASHRAE Guide and Data Book, Chapter 65, Tables 2 and 3. The specific gravity is the ratio of the density of a substance to the density of water. Thus, the density of the substance can be determined by multiplying its specific gravity by the density of water, which is taken as 62.4 lb/cu ft. The density varies with temperature. For water, the standard value of 62.4 lb/cu ft. is taken at 39.2°F. This will decrease to about 62.0 lb/cu ft at 100°F and will continue to decrease at higher temperatures.

For gases and vapors, the variation of density with temperature, and pressure, is very significant. Pressures less than about 500 psi will have negligible effect on the density of a liquid and pressures of several thousand psi are necessary to have a significant effect on the density of a solid.

Since the amount of heat transferred is dependent on the difference in temperatures across the substance through which the transfer will occur, the temperature of the earth is also of concern in the analysis of the shelter thermal environment. The earth temperature to be expected may be estimated from soil temperature data published by the U. S. Weather Record Center, Asheville, North Carolina, or by information which may be locally available for the site of the shelter. In dual purpose shelters, however, the earth temperature adjacent to the shelter walls will change after the shelter area has been occupied during its normal function and will thus be greater than the temperature of undisturbed earth.

Figure 5.3, reproduced from Reference 17, shows the maximum soil temperatures for the month of July for a range of depths for several soil stations, Figure 5.4, also from Reference 17, shows a typical cyclic variation in soil temperature for an area near Lexington, Kentucky. Shown are soil temperatures at the surface, 5 ft. depth and 10 ft depth and the mean air temperature, solar energy and precipitation. Note that the solar energy reaches its peak value during June and July but the soil surface temperature does not reach its peak until somewhat later. The peak temperature at 5 ft does not occur until about a month after the surface peak and the peak at 10 ft does not occur until October. This illustrates the time required for the incident solar energy to penetrate into the ground. Notice also that the range of temperature variation in the annual cycle is smaller with successively lower depths as would be expected.

The annual fluctuation of earth temperatures may penetrate to depths of 40 ft. or more, depending on the diffusivity of the soil. Temperatures also fluctuate on a daily basis but this effect will penetrate only 2.5 to 3 ft below the surface in most cases. Since a below grade shelter would normally have at least 3 ft. of earth cover, the diurnal temperature fluctuation of the earth may be neglected.

The thermal environment of any shelter is a balance of the heat generated in the shelter, the heat transferred to the ventilating air, and the heat conducted to and from the surrounding materials. Each of these may include sensible heat and latent heat components which vary with time. The analysis of the shelter-earth system is, therefore, a problem in transient heat conduction.

Unfortunately, the transient heat conduction analysis is very complex and is best solved by the use of a computer. Even then it is necessary to make certain simplifying assumptions. Shelter environments have been analyzed by use of both digital and analog computer techniques and the results show a reasonable degree of correlation with the results of experimental measurements using both human and simulated occupants.

On the basis of the analytical and experimental results, some general conclusions can be stated:

1. Ventilation rates should be analyzed for heat transfer as well as for control of the chemical environment.
2. Shelters should be located as deep as practicable below grade in the design of new buildings, in order to take advantage of the lower ground temperatures. (The protection factor would also be increased.) The cost of mechanical cooling may, however, preclude going to the expense of deep excavation.
3. Shelter materials with high thermal conductivity should be used.
4. The inside surface area per person should be made as large as possible.

From the standpoint of control of the thermal environment, shelters for a small number people will require the lowest ventilation rates, on a per capita basis. This is because the shelter surface area per person will be

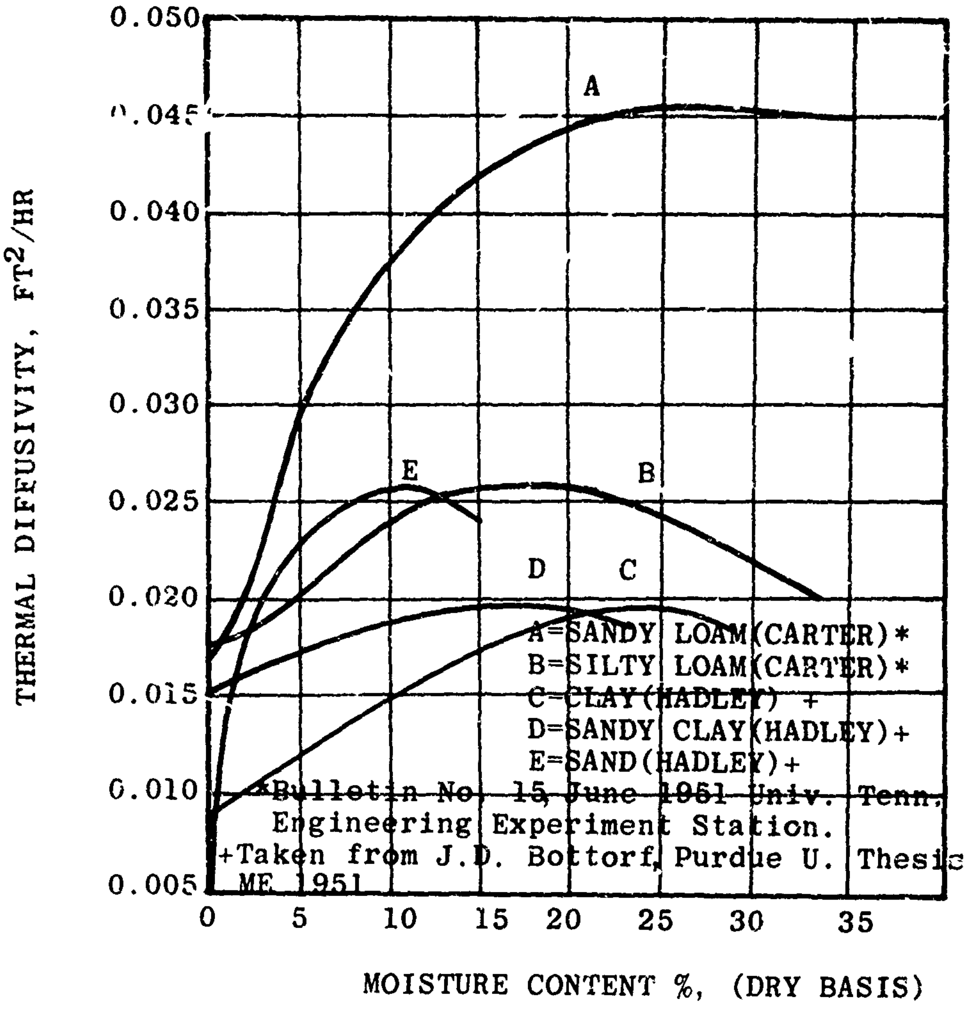


FIGURE 5.1 - Thermal Diffusivity as a function of moisture content

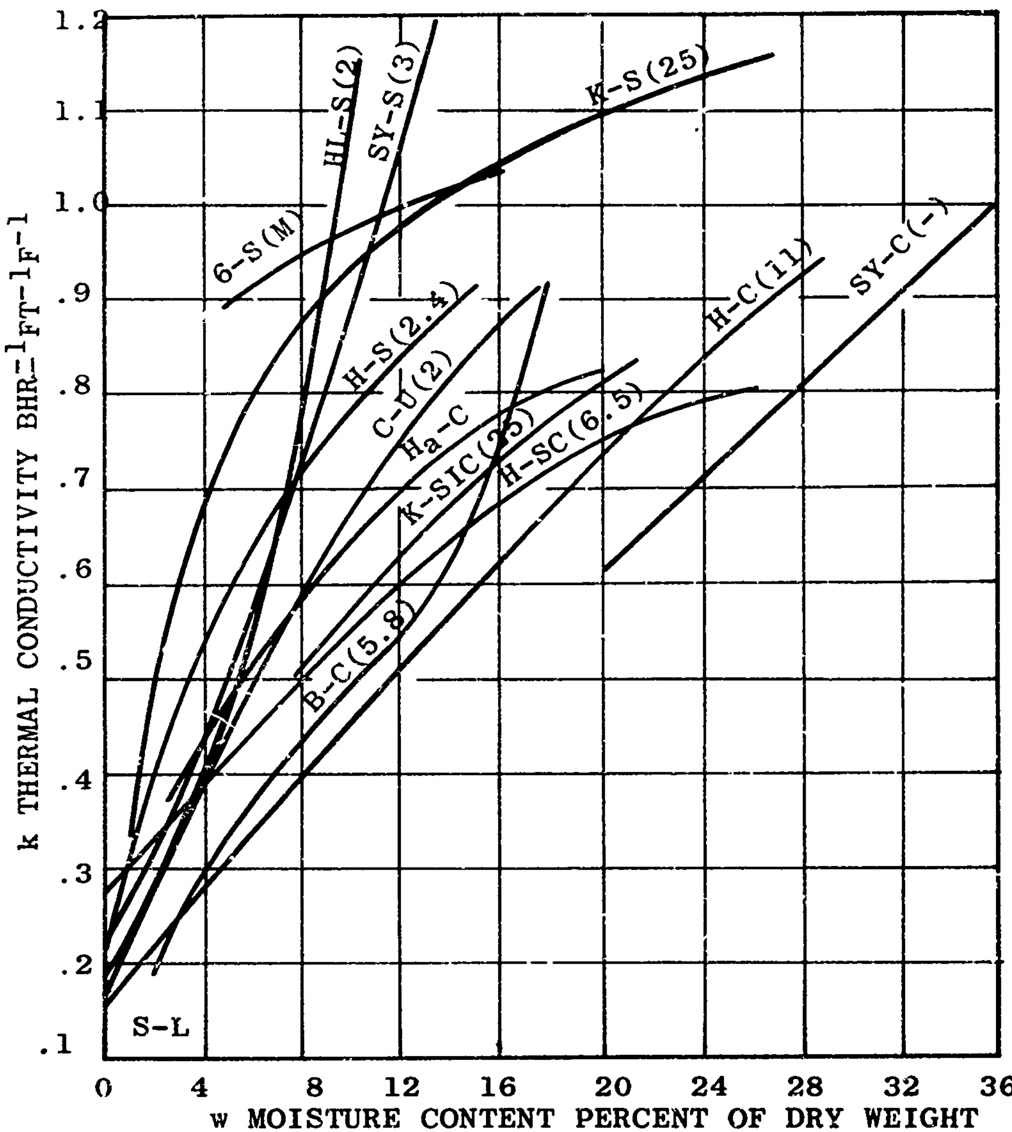
TABLE 5.2

THERMAL CONDUCTIVITY, SPECIFIC GRAVITY AND SPECIFIC HEAT OF SOME COMMON MATERIALS*

Material	Thermal Conductivity	Specific Gravity	Specific Heat, c_p
Water	0.330 at 32°F 0.356 at 86°F	1.00 .998	1.000 1.000
Brickwork	0.33 - 0.92	1.85 - 2.00	0.2
Cement	0.017	1.5 - 2.4	0.186
Clay	-----	1.28	0.224
Concrete	0.5 - 0.75	1.5 - 2.4	0.156
Earth (dry, packed)	0.022	1.5	0.2**
Limestone	0.3 - 0.75	2.1 - 2.8	0.217
Plaster	0.25 - 0.05	-----	-----
Sand	0.188	1.4 - 1.9	0.191
Wood, Oak	0.085 - .125	0.65 - 0.84	0.570
Fir	0.094	0.40	0.65
Pine	0.065 - 0.085	0.43 - 0.67	0.67
Aluminum	122.0	2.55 - 2.80	0.226
Asbestos	0.09	2.1 - 2.8	0.25
Copper (cast rolled)	224.0	8.8 - 8.9	-----
Steel (cold drawn)	28.0	7.83	0.12

*Abstracted from 1963 ASHRAE Guide and Data Book, Chapter 65, Tables 2 and 3

**Value not taken from Reference cited.



Summary of thermal conductivity As a function of mositure content for various soils as measured by several investigators (Taken from J.D. Bottorf, Purdue, University Thesis, 1951.)

<u>Explanation of Symbols</u>
<u>First Symbol, Investigator</u>
B-Bottorf
C-Coogan(9)
G-Gemant(10)
H-Hadley(7)
H_aHarsem(1)
HL-Hooper&Lepper(8)
K-Kersten(2)
SY-Smith & Yamauchi(6)
<u>Second Symbol, Soil Type</u>
S-Sand
SC-Sand Clay
SIC-Silty Clay
C-Clay
SL-Sandy Loam
L-Laom
U-Unspecified
<u>Third Symbol</u>
Numbers represent average percent Deviation of data from the mean curve shown
"M" indicates Calculated values based upon a model

FIGURE 5.2-Soil thermal conductivity vs. moisture content taken from Bottorf's Thesis

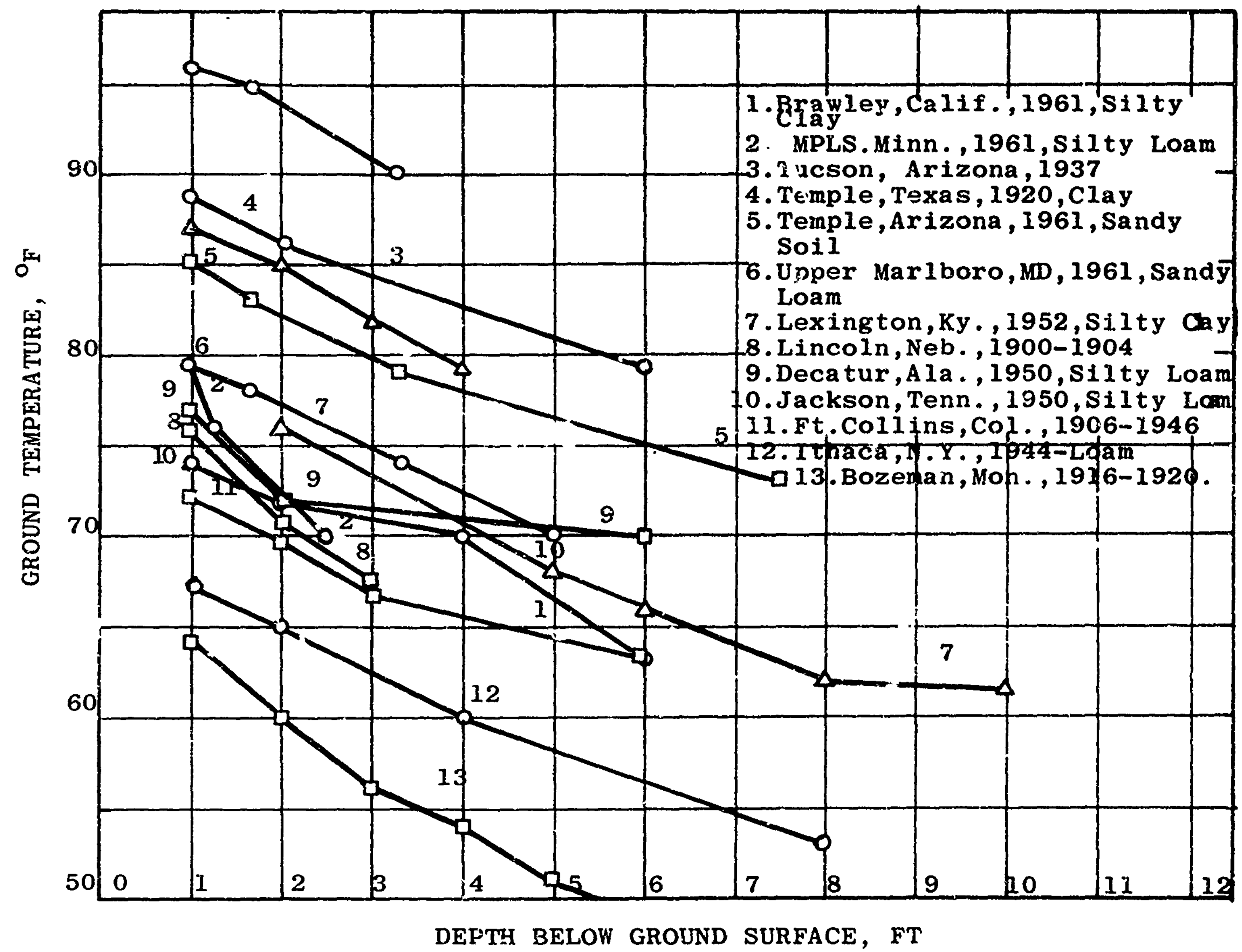


FIGURE 5.3 - Typical soil temperature profile in July at several selected soil stations in the United States

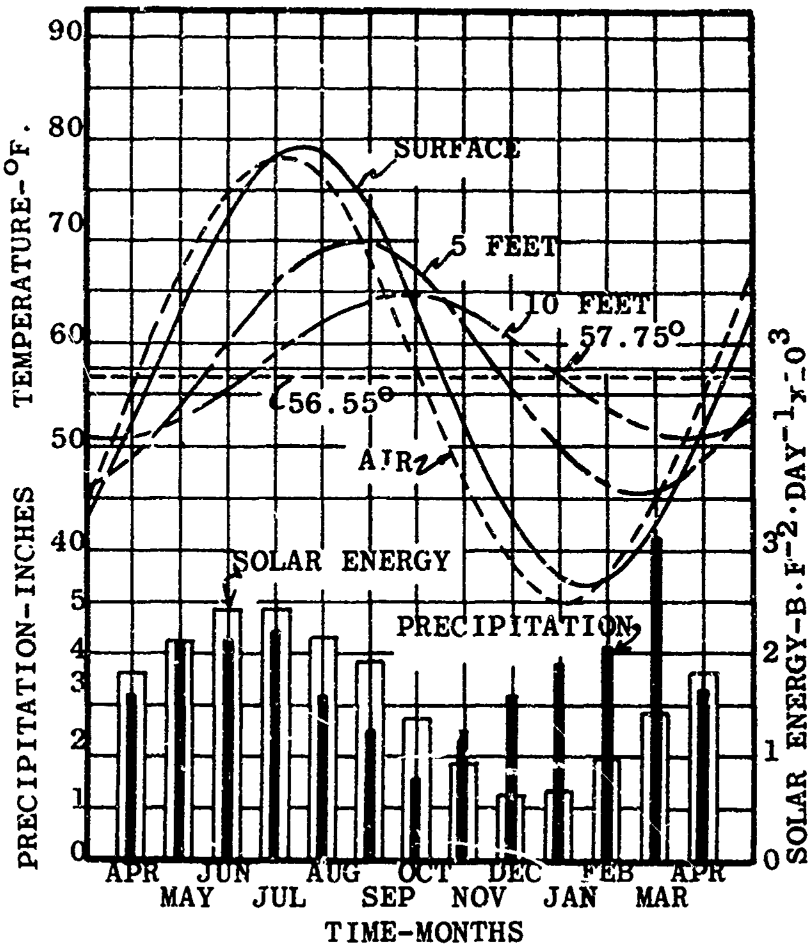


FIGURE 5.4 - Annual variation of soil temperature, mean air temperature, solar energy and precipitation (Prepared by Penrod for soil near Lexington)

large and the heat conduction to the surroundings depends on the number of square feet through which it can be transferred. Thus, the heat conduction per person is large and less heat has to be removed by the ventilation air. In larger shelters the surface area per person is reduced and hence the per capita heat loss to the earth is less. So more heat must be removed by the ventilation air, necessitating higher rates of ventilation.

Also, in the large shelters, the large amounts of heat transferred to the earth will increase earth temperatures adjacent to the shelter. This will decrease the temperature differential and reduce the amount of heat which can be transferred. Thus, heat conduction effects decrease significantly during the period of shelter occupancy. This is not so likely to affect the smaller shelter to the same extent.

The energy balance for a shelter can be written in the following simplified form:

$$Q_g + Q_g' = Q_v + Q_w + Q_R \qquad \text{(Eq. 5.2)}$$

Where:

Q_g = human metabolic heat, Btuh per person

Q_g' = heat generated by lights, cooking appliances, motor driven equipment, auxiliary power apparatus, etc., Btuh per person

Q_v = heat carried out by ventilation air, Btuh per person

Q_w = conduction heat loss to surrounding media, Btuh per person

Q_R = heat absorbed by cooling equipment, Btuh per person

The equation indicates the three possible methods of dissipating heat from the shelter are (1) cooling by ventilation air (2) cooling by heat conduction to the surroundings and (3) cooling while dehumdifying.

Dehumidification without cooling, such as by the use of a desiccant, might be considered under Method 3 but usually it will tend to increase rather than decrease the effective temperature in the shelter since the latent heat given up by the water vapor as it is absorbed remains in the shelter, causing an increase in dry-bulb temperature.

In the above equation, most of the factors have both a sensible heat and a latent heat component. In addition, the heat loss to the ventilation air and to the surrounding media are time dependent so that a complete analysis of the equation becomes very complex. However, simplified mathematical analyses have been made for three different cases:

1. no conduction heat loss to the surrounding media

2. no ventilation heat loss (buttoned-up condition) with infinitely large surrounding media of initially uniform temperature, and

3. sensible heat exchange of shelter with ventilation air and with large surrounding media with constant and uniform temperatures.

In all three analyses it is assumed there is no heat absorbed by cooling equipment.

CASE 1. NO CONDUCTION HEAT LOSS TO SURROUNDINGS

This analysis might apply to an underground shelter located in a region with high earth temperatures so that heat dissipation through the walls would be negligible. In this case Equation 5.2 would be reduced to:

$$Q_g + Q_g' = Q_v$$

In other words, all of the heat would have to be dissipated by the ventilation air.

The human metabolic heat consists of sensible and latent heat, the proportions being dependent on the dry-bulb temperature of the air as indicated in Table 3.6. For a sedentary adult with a total metabolic heat loss of 400 Btuh, the sensible and latent heat can

be approximated by the following equations:

$$q_s \approx 10(100-t_a) \qquad \text{(Eq. 5.3)}$$

$$q_l \approx 10\ t_a - 600 \qquad \text{(Eq. 5.4)}$$

Where t_a is the dry-bulb temperature of the air and is between 65°F and 110°F. The sensible heat balance, then is:

$$10(100 - t_a) + Q_g' = Q_v$$

The sensible heat lost to the ventilation air would be:

$$Q_v = m_a c_p (t_a - t_v)$$

Where m_a is the mass of air and c_p is the specific heat.

The mass of air will be the volume multiplied by the density (or divided by the specific volume). If the volume is given in cfm per person then:

$$m_a = G/V_a$$

For standard air c_p is 0.244 and V is 13.5

$$m_a c_p = (G)(60)(0.244)/13.5 = 1.08\ G$$

$$\left[\frac{ft^3}{min}\right]\left[\frac{min}{hr}\right]\left[\frac{Btu}{lb - {}^oF}\right]\left[\frac{lb}{ft^3}\right] = \frac{Btu}{hr\ {}^oF}$$

Where:

G = ventilation rate, cfm per person

c_p = 0.24 Btu/lb - °F for air

V_a = average specific volume of air, cu ft/lb

Now:

$$10(100 - t_a) + Q_g' = 1.08\ G\ (t_a - t_v)$$

Where t_a is the dry-bulb temperature of the shelter air and t_v is the dry-bulb temperature of the ventilation air. Rearranging and solving for t_a gives:

$$t_a = \frac{Q_g' + 1.08\ G\ t_v + 1000}{1.08\ G + 10} \qquad \text{(Eq. 5.5)}$$

Assuming that the heat gain from lights and other equipment is all sensible heat, the latent heat balance is:

$$10t_a - 600 = m_a h_{fg}\ (W_a - W_v)$$

Where:

m_a = mass of dry air = 60 G/V_a = lb/hr

h_{fg} = latent heat of vaporization of water, taken as approximately 1060 Btu/lb

W_a = humidity ratio of shelter air, lb vapor/lb dry air

W_v = humidity ratio of ventilation air, lb vapor/lb dry air

Then:

$$10t_a - 600 = \frac{60\ G\ 1060}{V_a}\ (W_a - W_v) \approx 4700\ G\ (W_a - W_v)$$

Rearranging gives:

$$W_a = W_v + \frac{10\ t_a - 600}{4700\ G} \qquad \text{(Eq. 5.6)}$$

Where W_v is assumed to be constant.

An example will serve to show the application of equations 5.5 and 5.6 in the determination of shelter conditions.

<u>EXAMPLE 5.1</u>: A shelter is supplied with air at 80°F db and 70°F wb at the rate of 10 cfm per person. The heat gain from lights and other equipment is 30 Btuh per person, all sensible heat. Determine the condition of the air in the shelter.

SOLUTION:

From Equation 5.5:

$$t_a = \frac{30 + (1.08)(10)(80) + 1000}{(1.08)(10) + 10} = 91^{o}F$$

From the psychrometric chart, W_v = 0.0135 lb vapor/lb dry air. Then, from Equation 5.6:

$$W_a = 0.0135 + \frac{(10)(91) - 600}{(4700)(10)} = 0.0135 + 0.0066$$

$$W_a = 0.0201 \text{ lb vapor/lb dry air}$$

Again going to the psychrometric chart, at 91°F db and W = 0.0201, the wet-bulb temperature is 80.4°F and the dew point if 77°F. From Figure 3.2 the effective temperature is estimated at 84.5°FET.

By Equation 3.2 the effective temperature is calculated as:

$$ET = 0.4\ (91 + 80.4) + 15 = 83.56^{o}F$$

which agrees with the value read from Figure 3.2 within one degree.

CASE 2. NO VENTILATION HEAT LOSS

The simplified mathematical analysis has been made for a "buttoned-up" shelter (no ventilation) located deep underground so that heat exchange near the surface does not affect the shelter environment. This assumption will be reasonably accurate for shelters located 3 feet or more below the ground surface, except in cases of large surface temperature increases due to surface mass fires.

The transient heat conduction equations have been solved for three simplified shelter models in order to calculate the change in shelter dry-bulb temperature and inner surface temperature from an initially uniform earth temperature.

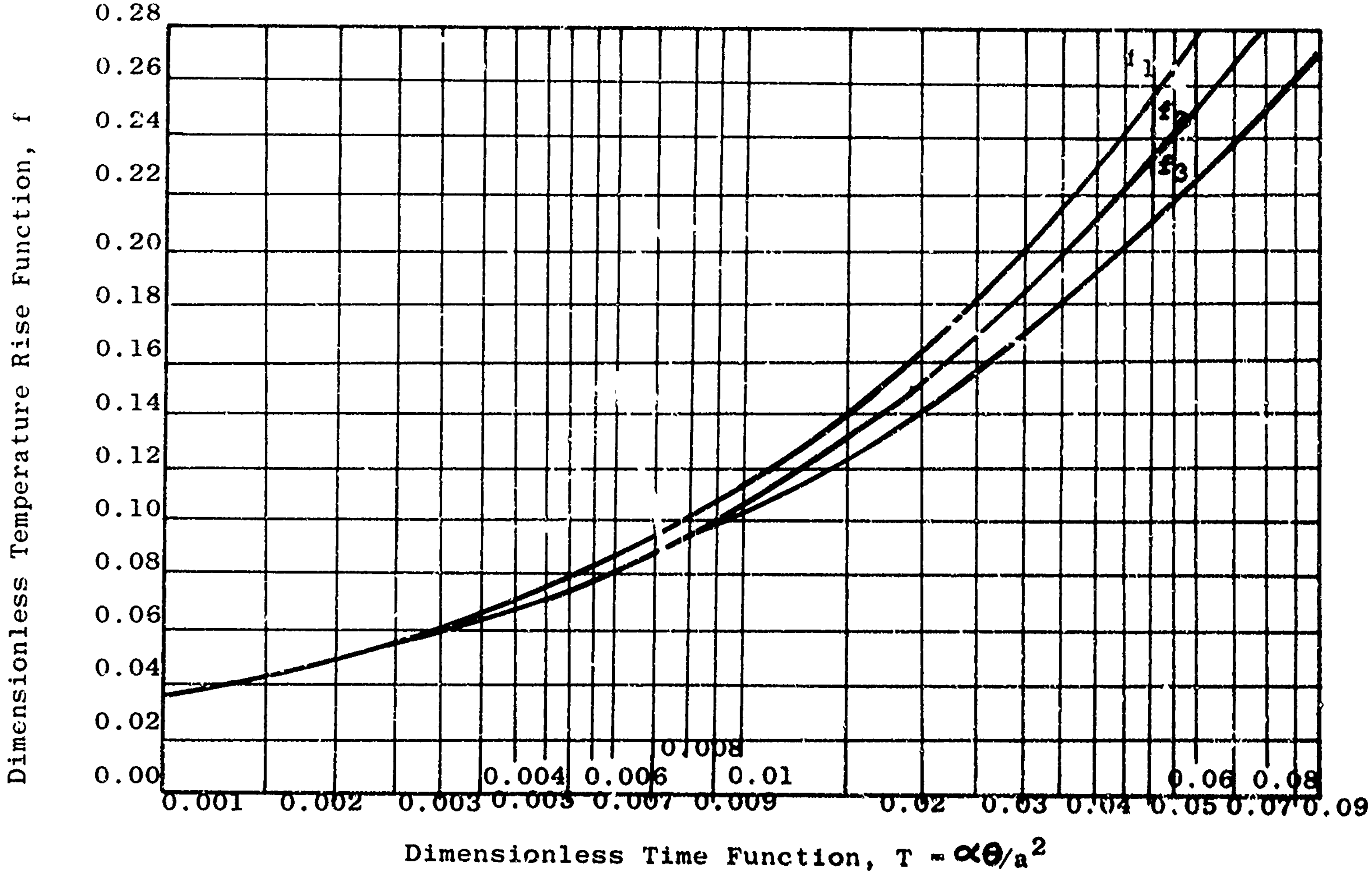


FIGURE 5.5 -- TEMPERATURE RISE FUNCTION FOR UNDERGROUND SEALED SHELTERS

The three simplified models are:

1. One-dimensional plane wall model. This model may be applied to large shelters where corner heat flow effect is negligible;

2. Cylindrical model, which will approximate a long tunnel;

3. Spherical model, which will give a good approximation for a small, family size shelter.

Empirical functions have been developed for use in mathematical analyses for each of these simplified models (18, 19, 20). The first of these is a dimensionless temperature rise function, values of which are plotted in Figure 5.5 for the three models; f_1 for the plane wall model, f_2 for the cylindrical model, and f_3 for the spherical model. They are shown plotted against a dimensionless time function, T, which can be computed from:

$$T = \alpha \theta / a^2 \qquad \text{(Eq. 5.7)}$$

Where:

T = time function, dimensionless

α = thermal diffusivity of soil, ft^2/hr

θ = elapsed time, hours

a = appropriate value of equivalent radius of the shelter model used, feet

The equivalent radius of the shelter model may be determined approximately from the following:

(Plane Wall Model) $a_1 = \sqrt{S_i}$ (Eq. 5.8)

(Cylindrical Model) $a_2 = \sqrt{S_c/\pi}$ (Eq. 5.9)

(Spherical Model) $a_3 = \sqrt{S_i/4\pi}$ (Eq. 5.10)

Where:

S_i = interior surface area of shelter, square feet

S_c = cross-sectional area of shelter, square feet

In order to dissipate a certain amount of heat by conduction through the shelter walls, the temperature difference between the interior and the exterior of the wall must be sufficient to provide the necessary thermal potential to effect the heat conduction, according to the basic heat transfer equation, Equation 5.1. If it is assumed that the earth temperature remains constant and the initial inner surface temperature is equal to the earth temperature, the rise in inner surface temperature can be expressed by:

$$t_w - t_o = \frac{Q\ a}{S_i\ k}\ f \qquad \text{(Eq. 5.11)}$$

Where:

t_w = final temperature of the inner surface, °F

t_o = initial temperature of the inner surface, °F

Q = total heat generated in the sealed up shelter, Btuh

a = equivalent radius of the shelter model, determined from Eq. 5.8, 5.9, or 5.10 for the model being used, feet

S_i = inner surface area of shelter, square feet

k = thermal conductivity of the soil, Btuh/ft - °F

f = value of temperature rise function for the model being used from Figure 5.5, dimensionless.

It has been found that the dew point temperature of the buttoned-up shelter air will be approximately the same as the average inner surface temperature and the dry-bulb temperature will be within a few degrees of the inner surface temperature (20). Thus the shelter effective temperature will be almost equal to the inner surface temperature under sealed-up conditions.

It is probable that, under "buttoned-up" conditions, the shelter air will quickly become saturated and will remain saturated as long as no ventilation air is

supplied. The shelter air will probably be at a somewhat higher temperature than the wall temperature and, consequently, condensation on the inner surfaces is to be expected. This is not necessarily detrimental as far as the thermal environment is concerned, although it may have an adverse physiological or psychological effect on the occupants. The only way to avoid condensation is to maintain the dew point temperature of the air below the temperature of the interior surfaces. During a sealed-up period this probably cannot be accomplished without some method of mechanical cooling.

EXAMPLE 5.2: Determine the effective temperature of a shelter after 24 hours of sealed up operation. The shelter is 10 ft long by 8 ft wide by 7 ft high. There are 6 occupants with an average metabolic rate of 400 Btuh per person. The earth temperature is 75°F and the soil diffusivity is 0.02. The conductivity is 0.75.

SOLUTION: For this small shelter the spherical model is used. The inner surface area is:

$$S_i = 2\left[(10)(7) + (8)(7) + (10)(8)\right] = 412 \text{ sq ft}$$

The equivalent radius, by Equation 5.10, is:

$$a = \sqrt{412/4\pi} = 5.72 \text{ ft}$$

The dimensionless time function is, by Equation 5.7:

$$T = \frac{(0.02)(24)}{32.7} = 0.0147$$

From Figure 5.5 the temperature rise function, f_3 is 0.122. Then, by Equation 5.11:

$$t_w - t_o = \frac{(6)(400)(5.72)}{(412)(0.75)}(0.122) = 5.4^{o}F$$

Assuming that the initial inner surface temperature is equal to the initial earth temperature gives:

$$t_w = t_o + 5.4^{o}F = 80.4^{o}F$$

The shelter effective temperature can be taken as 80.4°F.

EXAMPLE 5.3: An underground shelter, located at Lexington, Kentucky, is 100 ft long by 100 ft wide by 8 ft high, and contains 1000 occupants with an average metabolic rate of 400 Btuh per person. The shelter is in clay soil with 3 ft of earth cover. Determine the effective temperature after 48 hours of buttoned-up operation during the month of August.

SOLUTION: Assume a soil moisture content of 20% and from Figure 5.1, Curve C estimate the diffusivity as 0.018 and from Figure 5.2, Curve H-C (11) estimate the conductivity as 0.73.

The average depth of the shelter is about 7 ft. From Figure 5.4 the soil temperature at a 7 ft depth in August is estimated as 66°F.

The inner surface area of the shelter is:

$$S_i = 2\left[(100)(8) + (100)(8) + (100)(100)\right] = 23{,}200 \text{ sq ft}$$

Taking the plane wall model, the equivalent radius is, by Equation 5.8:

$$a = \sqrt{23{,}200} = 152 \text{ ft}$$

$$T = \frac{(0.018)(48)}{23200} = 0.000037$$

This is off the scale in Figure 5.5 so, by extrapolation, f_1 is estimated to be about 0.03. Now:

$$t_w - t_o = \frac{(1000)(400)(152)}{(23200)(0.73)}(0.03) = 108^\circ F$$

and:

$$t_w = t_o + 108 = 66 + 108 = 174^\circ F$$

In this example the answer obtained is obviously impossible. A temperature of 174°F cannot be produced by a heat source of only about 100°F, the occupants of the shelter. The reason for this is the value of f_1 which was obtained by extrapolation. For almost any realistic time duration of buttoned-up operation, the value of T for a plane wall model will be off scale

in Figure 5.5. Thus the values of f_1 will be questionable and can lead to unreliable solutions when the plane wall model is used. In the previous example the only reliable conclusion which can be drawn is that the shelter in question would have to have ventilation, or some means of cooling in addition to conduction to the earth long before the end of the 48 hour period.

It may be noted that the time involved, in this case, has very little effect on the solution. A reduction of time, even to as little as one hour, would not reduce T enough to have much effect on f_1, since, at low values of T, the curve in Figure 5.5 becomes almost horizontal. Thus f_1 will not be reduced enough to reduce the temperature rise to acceptable levels. The problem here, of course, is that there is not enough surface area per person to dissipate the metabolic heat to the surrounding earth.

CASE 3. VENTILATED SHELTER WITH EARTH CONDUCTION EFFECTS

In Case 1 it was assumed that there was no heat conducted to the earth and cooling was by ventilation only. In Case 2 it was assumed that there was no ventilation and cooling was by conduction to the earth only. In the normal operation of an underground shelter the thermal environment will probably be affected by both ventilation and earth conduction effects. The simplified analytical solution for this condition is developed in Reference 18 and modifications of it are presented in References 17 and 20.

The heat balance for this condition is:

$$Q_g + Q_g' = Q_v + Q_w \qquad \text{(Eq. 5.12)}$$

Where the symbols are as defined for Equation 5.2 and it is assumed that there is no heat absorbed by cooling equipment.

It may be assumed that heat from lights and mechanical equipment will be generated at a reasonably steady rate. However, all of the other terms are time dependent. Equation 5.12 can be written in the form:

$$10(100 - t_a) + Q_g' = 1.08\ G(t_a - t_v) + h\ S_p(t_w - t_a) \qquad \text{(Eq. 5.13)}$$

Where Q_g has been replaced by the sensible portion of

the human metabolic heat, Equation 5.3; Q_v has been replaced by 1.08 G $(t_a - t_v)$ as explained in the derivation of Equation 5.5; Q_w has been replaced by h S_p $(t_w - t_a)$ where:

h = surface heat transfer coefficient, Btu/(hr)(ft^2)(°F)

S_p = inner surface area of shelter, square feet per person

t_w = inner wall temperature, °F

t_a = shelter air temperature, °F

The last term is the heat transferred from the shelter air to the wall due to a difference in temperature between the air and the surface of the wall. It is apparent that this must also be equal to the heat conducted through the wall to the earth.

For an initially unoccupied shelter it may be reasonably assumed that the air temperature and the wall temperature are very close to being the same and that, furthermore, they will be very close to the temperature of the earth. As occupants and mechanical equipment dissipate heat to the shelter air the temperature will rise. The increased air temperature will cause a transfer of heat to the walls, and through the walls to the earth. At the same time ventilation air will remove some of the heat generated in the shelter. Obviously the shelter air temperature will vary with time and the solution of Equation 5.13 becomes quite complex.

In order to arrive at a method of solution certain simplifying assumptions must be made, in addition to those made previously.

1. No temperature gradient within the shelter air;
2. No condensation of water vapor on the inner wall surface;
3. The body heat loss is linear with respect to air temperature, as indicated in Equations 5.3 and 5.4;

4. The surface heat transfer coefficient is uniform for the inner wall surface;

5. The temperature of the ventilation air is constant.

With these assumptions the solution can be obtained in terms of parameters which have been empirically determined. The rise of the shelter air dry-bulb temperature and inner surface temperature is determined in terms of a dimensionless temperature rise function, $\phi 1$, $\phi 2$, or $\phi 3$ corresponding to the plane wall model, the cylindrical model and the spherical model respectively. $\phi 1$ is plotted in Figure 5.6, $\phi 2$, in Figure 5.7 and $\phi 3$ in Figure 5,8. All three figures have been redrawn from Reference 20.

In these figures, ϕ is plotted as a function of T and N. The dimensionless time function, T, has been previously defined as being equal to $\alpha \theta / a^2$, where the appropriate value of a would be inserted for the shelter model being used. The second parameter, N, is also dimensionless and involves the heat transfer characteristics of the shelter. For a 400 Btuh occupant, it is evaluated by

$$N = h \left[\frac{a}{k}\right] \left[\frac{1.08 \text{ G} + 10}{1.08 \text{ G} + 10 + hS_p}\right] \qquad \text{(Eq. 5.14)}$$

Where all the terms are as previously defined.

With values of T and N having been determined, enter the appropriate chart to find ϕ.

Then:

$$t_w - t_o = U_o \phi \qquad \text{(Eq. 5.15)}$$

Where:

t_w = final temperature of inner surface, ^oF

t_o = initial temperature of inner surface, ^oF

U_o is defined as:

$$U_o = \frac{Q_g' + (10)(100 - t_o) + 1.08 \text{ G}(t_v - t_o)}{1.08 \text{ G} + 10} \qquad \text{(Eq. 5.16)}$$

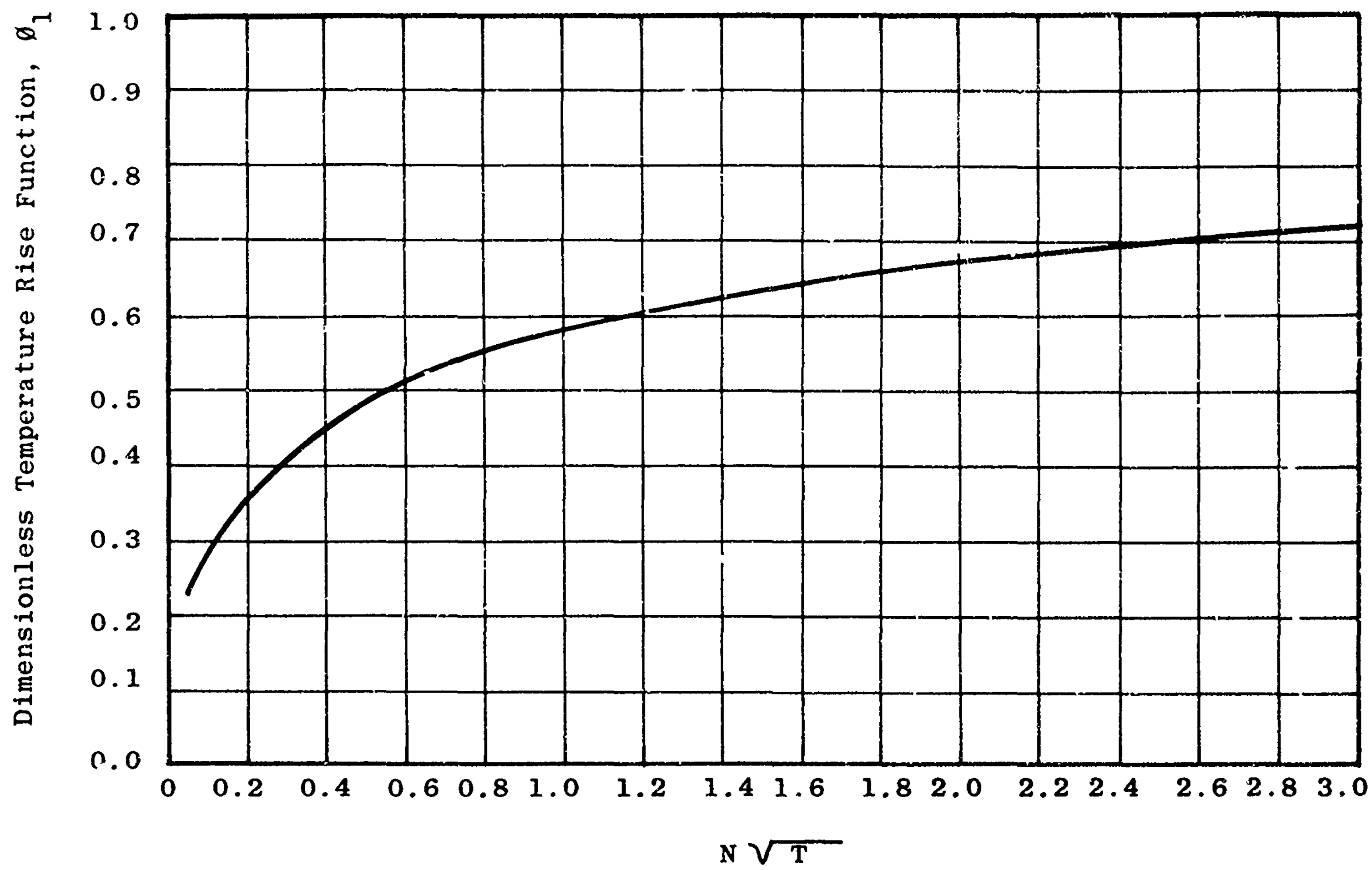
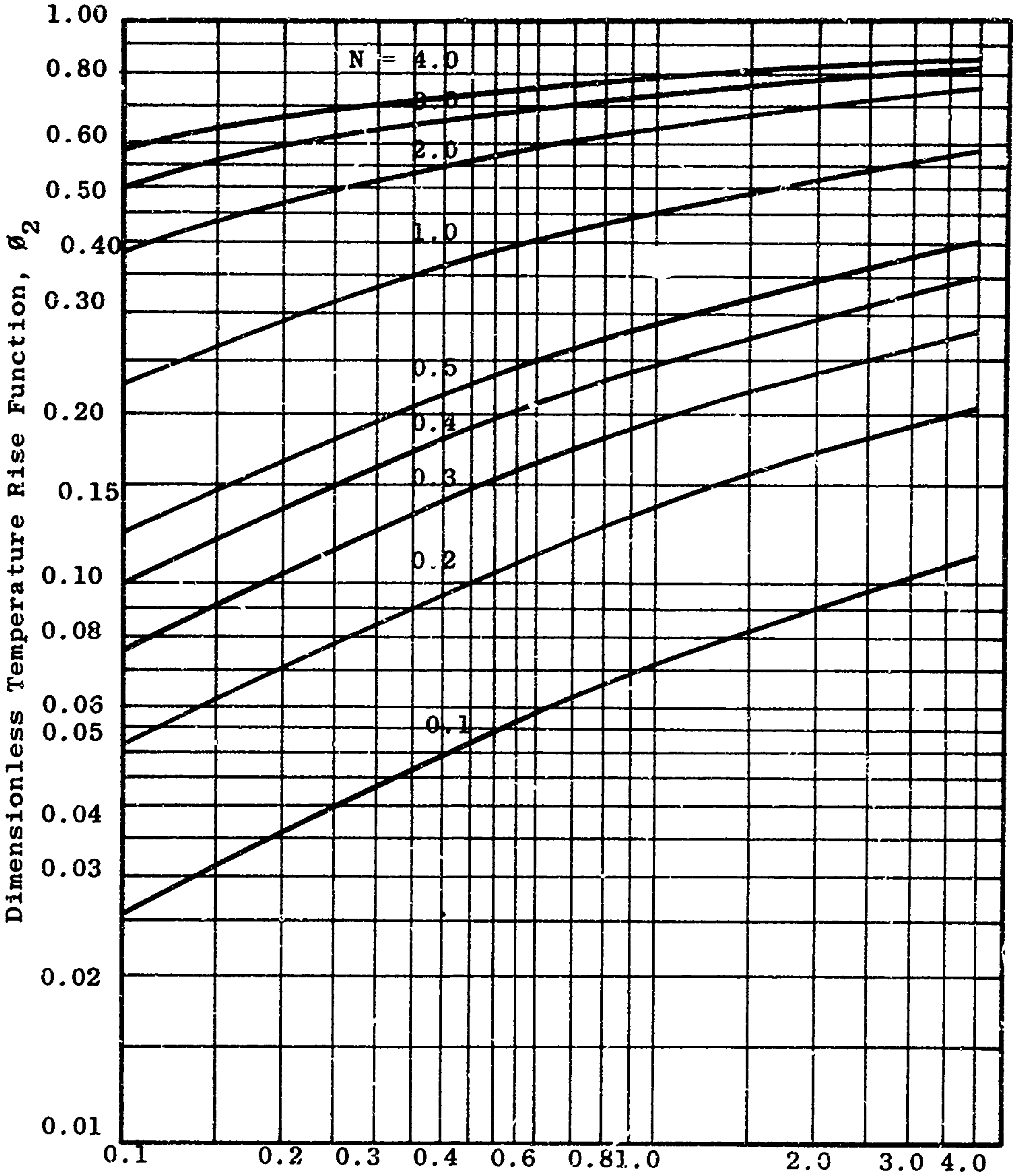


FIGURE 5.6 -- TEMPERATURE RISE CHART FOR VENTILATED UNDERGROUND SHELTER, PLANE WALL MODEL
(Redrawn by permission from ASHRAE Guide and Data Book, 1964)



Dimensionless Time Function, $T = \alpha\theta/a^2{}_2$

FIGURE 5.7 -- TEMPERATURE RISE CHART FOR
VENTILATED UNDERGROUND SHELTER,
CYLINDRICAL MODEL
(Redrawn by permission from ASHRAE Guide and Data Book, 1964)

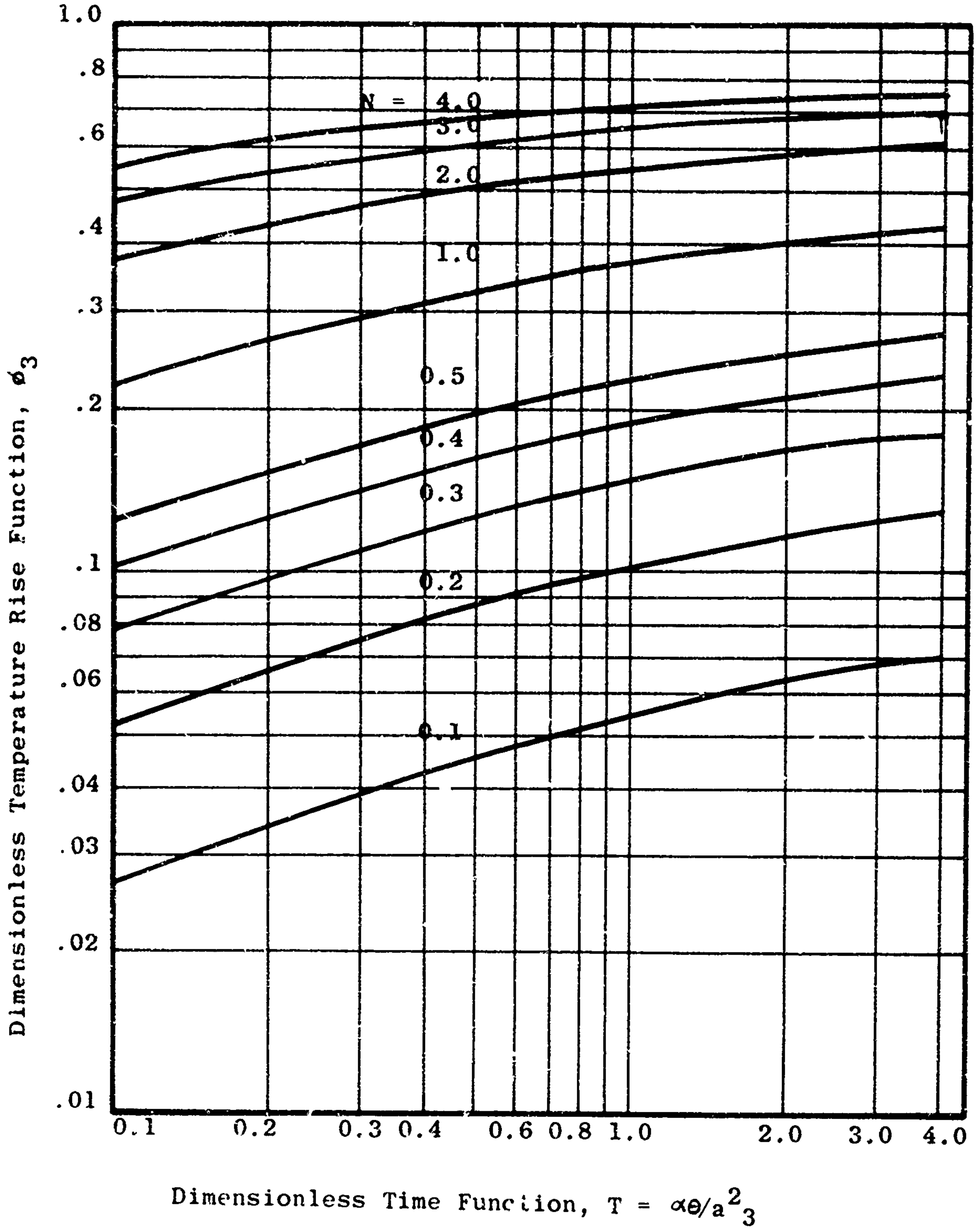


FIGURE 5.8--TEMPERATURE RISE CHART FOR VENTILATED UNDERGROUND SHELTER, SPHERICAL MODEL

(Redrawn by permission from ASHRAE Guide and Data Book, 1964)

Each term in the numerator of Equation 5.16 has dimensions of Btuh per person. The denominator has dimensions of Btuh per person per degree F. Consequently U_o has dimensions of degrees F, which is required for Equation 5.15 to be dimensionally consistent.

Now another dimensionless parameter is defined as:

$$n = \frac{h\ S_p}{1.08\ G + 10 + h\ S_p} \qquad \text{(Eq. 5.17)}$$

The rise in dry-bulb temperature of the shelter air may now be computed from:

$$t_a - t_o = \left[(1 - n) + n\phi\right]\ U_o \qquad \text{(Eq. 5.18)}$$

Once the dry-bulb temperature is known, the effective temperature can be determined if the humidity ratio is known. Since it was assumed that there was no condensation of water vapor, the latent heat transfer can be assumed to be small, and the humidity ratio can be approximated by Equation 5.6:

$$W_a = W_v + \frac{10\ t_a - 600}{4700\ G} \qquad \text{(Eq. 5.6) (Repeated)}$$

<u>EXAMPLE 5.4</u>: Use the shelter as described in Example 5.3 and determine the effective temperature at the end of 14 days occupancy if the ventilation rate is 10 cfm per person, and 30 Btuh per person is added by lights and mechanical equipment.

<u>SOLUTION</u>: From Example 5.3, $\alpha = 0.018$, $k = 0.73$, $S_i = 23{,}200$ sq ft, $a = 152$ ft, and $t_o = 66^oF$. From Table 5.1 the 5% summer climatic conditions at Lexington, Kentucky are 90°F dry-bulb and 76° wet-bulb, which can be used as the condition of the supply air.

$$T = \frac{\alpha\theta}{a^2} = \frac{(0.018)(14)(24)}{23{,}200} = 0.00026$$

$$S_p = 23{,}200/1000 = 23.2 \text{ sq ft/person}$$

The surface heat transfer coefficient, h, is assumed at 1.5 Btu/(hr) (sq ft) (°F). Then:

$$N = 1.5\left[\frac{152}{0.73}\right]\left[\frac{(1.08)(10) + 10}{(1.08)(10) + 10 + (1.5)(23.2)}\right] = 116.7$$

$$N\sqrt{T} = 116.7 \quad \sqrt{0.00026} = 1.88$$

From Figure 5.6, $\phi = 0.67$

$$U_o = \frac{30+(10)(100 - 66) + (1.08)(10)(90 - 66)}{(1.08)(10) + 10} = 30.2$$

$$t_w - t_o = (30.2)90.67) = 20.3^oF$$

$$t_w = 66 + 20.3 = 86.3^oF$$

$$n = \frac{(1.5)(23.2)}{(1.08)(10) + 10 + (1.5)(23.2)} = 0.625$$

$$t_a - t_o = \left[(1 - 0.625) + (0.625)(0.67)\right] 30.2 = 24^oF$$

$$t_a = 66 + 24 = 90^oF$$

From the ASHRAE psychrometric chart:

$$W_v = 0.0162$$

and by Equation 5.6:

$$W_a = 0.0162 + \frac{(10)(90) - 600}{(4700)(10)} = 0.02259$$

Then, from the psychrometric chart, at 90°F dry-bulb and humidity ratio of 0.02259, the dew point is 80.3°F and the wet-bulb is about 82.5°F. From Figure 3.2, the effective temperature is about 85°F.

Checking the results of this example against the curves of Figure 4.4 (the conditions at Lexington, Kentucky, should be very closely the same as at Louisville) shows that a ventilation rate of 10 cfm would give a reliability of not exceeding 85°FET of about 95 percent. This is read from the 86° curve in Figure 4.4 since the figure is based on the unadjusted method. Since the 5 percent design data were used in the example problem this is about what would have been expected. Actually the 5 percent design value is based on only the four summer months so that the reliability based on 365 days would be about 98 percent.

In order to have a reliability of 90 percent of not exceeding 82°FET Figure 4.4 indicates a ventilation rate of about 13 cfm per person. When a rate of 15 cfm per person is used in Example 5.4, however, there

is no significant improvement in the shelter effective temperature. This is due to the difference in the condition of the ambient air for the two methods. In the example problem, the values from Table 5.1 of 90° dry-bulb and 76° wet-bulb give a still-air effective temperature of 82°. Using this value of outside ET and an inside ET of 82° also, Figure 4.3 indicates that the ventilation rate would have to be infinite.

This illustrates the danger of using the data from Table 5.1 for design purposes. If, however, they are used the error involved should be on the safe side since ventilation rates, in general, would be overestimated. For an underground shelter in contact with the earth the ventilation rate determined by a Case 3 solution should be less than that given by the simplified method of Chapter IV due to the effect of heat conduction to the earth, provided that the inlet air conditions are the same in both methods.

The preceding methods of calculation are based on simplified models and therefore, can be relied on only for approximations of the thermal conditions to be expected in a shelter. However the solutions obtained by using them have been shown to correlate very closely with the results of both human and simulated occupancy tests (22).

From the discussion it is evident that the thermal conditions in the shelter will be influenced to a large extent by the thermal properties of the soil surrounding the shelter and the initial earth temperature. The length of time the shelter is occupied (stay time) will also affect the temperature rise to be expected. Both the thermal conductivity and the diffusivity vary with the moisture content of the soil. It is very improbable that the actual moisture content of the soil at the time the shelter must be occupied can be predicted with any degree of certainty. Also it is possible only to make an estimation of the probable earth temperature and the conditions of the ambient air which might exist at the time the shelter is needed. Furthermore, although a shelter may be designed for a certain capacity, there is no assurance that the number of occupants will be exactly the number anticipated. For these reasons an approximation of the thermal conditions to be expected, is the best that can be done at the design stage and the methods presented here should be adequate for the purpose.

The preceding discussion has shown that the earth conduction effect may be adequate, in conjunction with sufficient ventilation air, to maintain a tolerable thermal environment in a below grade shelter. Therefore, in locating below grade shelters, every effort should be made to select a location which will provide a relatively low earth temperature, and advantage should be taken of any available shade or grass cover in order to reduce the heat gain from the surface of the earth.

When the earth conduction effect and ventilation by outdoor air is not sufficient to maintain a tolerable thermal environment, or when ventilation air is not available, it may be necessary to provide some form of supplemental cooling. In this case the method of estimating the shelter conditions presented previously can still be applied by using the conditions of the supply air from the cooling system, instead of ambient air conditions, as the ventilation dry-bulb temperature and humidity ratio in the previous equations.

In this connection it should be mentioned that the configuration of the ventilation air intake system can affect the conditions of the supply air so that the condition of ventilation air entering the shelter is significantly different from the condition of the atmospheric air. Relatively long runs of duct work from the ventilation intake fixture to the shelter may result in cooling the supply air, if the ground temperatures are low enough. If the supply air duct is brought in through the shelter entrance way it is possible that the conditions in the entrance way can have a warming effect on the supply air, especially if there is an auxiliary power unit or other mechanical equipment located in the entrance passage. Such equipment will dissipate part of its heat by radiation to the air in the passage and some of this heat may be picked up by the ventilation air.

HEAT CONDUCTION TO BELOW GRADE SHELTERS FROM MASS FIRES

When the surface of the earth, or roof slab, above an underground shelter is covered with burning or smoldering material, as might occur due to a mass fire, the

temperature of the lower slab surface will slowly rise and may continue to rise for several hours after the fire has burned out due to the time required to conduct heat through the overburden or slab. The temperature rise of the ceiling can be estimated by the method presented in Reference 20, using Figure 5.9 which has been redrawn from this reference.

The method is based on a hypothetical fire curve which assumes a sudden outside surface temperature rise to fire temperature (t_F) at time, θ, followed by a linear return to initial surface temperature before the fire (t_o). The time required for this to occur is the fire period, θ_o. The temperature of the lower surface (t), can be computed from the dimensionless temperature rise function, ϕ_F, plotted as the ordinate in Figure 5.9, for any time, θ, after the start of the fire. The ratio of time, θ, to the fire period, θ_o, is the dimensionless time function, Y, plotted as the abscissa.

$$Y = \theta/\theta_o \qquad \text{(Eq. 5.19)}$$

$$\phi_F = \frac{t - t_o}{t_F - t_o} \qquad \text{(Eq. 5.20)}$$

The length of time required for the heat to be conducted through the earth, or slab, will depend on the thermal diffusivity of the material, the length of the fire period, and the thickness of the material. These factors are expressed by the dimensionless function T' as follows:

$$T' = \frac{\alpha \theta_o}{L^2} \qquad \text{(Eq. 5.21)}$$

Where α = thermal diffusivity, ft^2/hr

θ_o = fire period, hours

L = thickness of material, feet

Curves for various values of T' are plotted in Figure 5.9. To find the ceiling temperature of the shelter at a time, θ, after the start of a fire, determine Y from Equation 5.19 and determine T'. Then, entering the figure at Y, locate the intersection with the T'

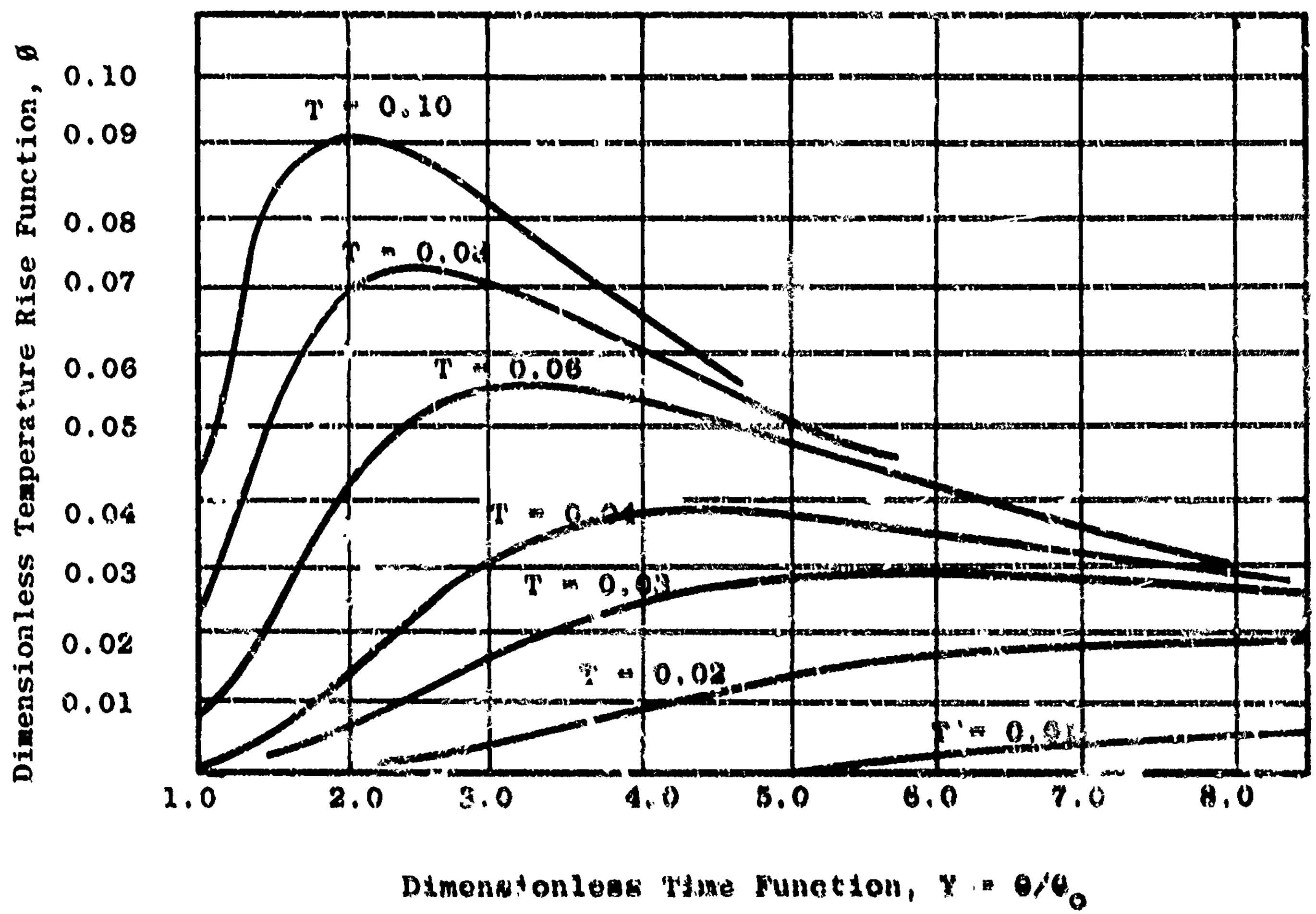


FIGURE 5.9 - TEMPERATURE RISE OF SHELTER CEILING DUE TO OVERHEAD FIRE

(Redrawn by permission from ASHRAE Guide and Data Book 1964)

curve ... read ... to read ... Substitute this value in ... 5-20 and, knowing the ... surface temper... and the fire temperature, t_F, solve for

EXAMPLE 5.5: Determine the ceiling temperature of a shelter with 3 feet of earth cover at a time 12 hours after the start of a surface fire. Assume a fire period of 8 hours and an initial surface temperature of 75°F. The maximum temperature of the fire is 1600°F and the diffusivity of the earth is 0.045.

SOLUTION: From Equation 5.19:

$$Y = 12/8 = 1.5$$

T' is determined from Equation 5.21.

$$T' = (0.045)(8)/3^2 = 0.04$$

Entering the figure at $Y = 1.5$ determine $\phi = 0.006$. By Equation 5.20:

$$0.006 = \frac{t - 75}{1600 - 75}$$

$$t = (0.006)(1600 - 75) + 75 = 9.15 + 75$$

$$t = 84.15^{\circ}F$$

EXAMPLE 5.6: Using the data from Example 5.5 determine the maximum ceiling temperature and the time after the start of the fire at which it occurs.

SOLUTION: The crest of each curve for T' occurs at the time when the ceiling temperature is a maximum. The crest of the curve for $T' = 0.04$ occurs at about $Y = 4.5$. The corresponding value of ϕ is about 0.038. Then:

$$0.038 = \frac{t - 75}{1600 - 75}$$

$$t = (0.038)(1600 - 75) + 75$$

$$t = 57.95 + 75 = 132.95^{\circ}F$$

The time at which this occurs is:

$$\theta = (8)(4.5) = 36 \text{ hours after the start of the fire.}$$

The method presented above will provide an estimate of the ceiling temperature at any given time but it will probably overestimate the temperature. Limited experimental evidence available indicates that ceiling temperatures will not increase to the extent indicated by the mathematical solution. This may be due, in part, to the assumption of a straight line fire curve, since it seems probable that the fire temperature will decrease exponentially rather than linearly. However, there are two important conclusions to be drawn from these calculations:

1. They demonstrate the benefits to be derived from heavy earth cover. If, in the example, two feet of earth cover had been used, instead of three feet, the value of T' would have been 0.08 and the maximum calculated temperature would occur sooner, at about 20 hours rather than 36 hours.
2. They indicate that the maximum temperature will, in most cases, occur well after the surface temperature has returned to normal. If a time, θ, equal to the fire period is selected, it can be seen from Figure 5.9, at Y = 1, that a value of T' greater than 0.04 will be necessary before there will be any increase at all in the shelter ceiling temperature. This would require a long fire period, shallow earth cover, or a high thermal diffusivity, or a combination of these factors. Present opinion, therefore, is that the heat conduction effects from a surface fire to a shelter with at least three feet of earth cover (or equivalent) will be negligible while the fire is burning.

The major problems connected with large scale fires are high temperature air and excessive carbon monoxide concentrations. Either or both of these conditions will require that the ventilation system be shut down unless a reliable source of air can be assured through a remote intake system. It is fortunate that the heat conduction effect will, in most cases, be insignificant during the time ventilation air might not be available. By the time the shelter

ceiling temperature rise becomes significant it will probably be possible to resume normal ventilation. However it could be that piles of rubble around the ventilation intake could smoulder for many hours, or even days, causing excessive carbon monoxide. In this case the shelter may still have to be buttoned up at the time the conducted heat reaches the shelter. In this situation it may become necessary to consider the possibility of venturing outside the shelter in order to clear the debris from around the intake fixture. This possibility indicates that the ventilation intake should be located as far as possible from any structures or other concentrations of combustible material.

Another possible approach is to use the methods and data for air conditioning calculations as presented in Chapters 25 and 26 of the 1958 ASHRAE Guide and Data Book. Care must be exercised, however, because the analysis for a shelter differs from a normal air conditioning problem in two important respects:

1. The conditions of the air in the shelter space are not known or predetermined, as is the case in air conditioning calculations.

2. In a shelter the major source of heat and moisture comes from the occupants and thus will vary with the number of occupants and with the dry-bulb temperature of the shelter air.

A possible approach would be to assume a maximum effective temperature which would not be exceeded, probably 82°FET, and then assume dry-bulb and wet-bulb temperatures which are likely to occur in the shelter to produce this effective temperature. With cooling by ventilation only, the shelter dry-bulb temperature is unlikely to be less than the supply air dry-bulb unless the supply air dew point is very low. Once this assumption is made the calculations can be carried out to determine the ventilation rate necessary to maintain these conditions. Since the maximum tolerable shelter conditions were assumed, the ventilation rate determined would be the minimum rate necessary.

VENTILATION OF ABOVE-GROUND SHELTERS

The simplified methods of calculation for below grade shelters as presented in the previous sections have been developed over a period of several years and have been proven to provide solutions within acceptable limits of accuracy.

The determination of required ventilation rates for above-ground shelters is complicated by the wide variety of possible configurations of the shelters. Such shelters are located in existing buildings, or will be included in new construction, and most of them were not designed with their shelter capability in mind. Essentially each one is a unique problem and must be analyzed on an individual basis. Also they are exposed to solar heat gains, which were not included in the calculation procedures for underground shelters.

In these shelters there would be no surrounding earth to provide a sink for the dissipation of heat. On the contrary, the surrounding media is atmospheric air which, under summer conditions, may be at a temperature greater than the shelter wall temperature and thus become a source of heat gain. The mass of building materials will have a small capacity to absorb heat but this will not be sufficient to have any significant effect on the thermal conditions in the shelter area after the first few hours of occupancy.

Simulated occupancy tests of above-ground shelters in the core areas of large buildings have shown that very nearly adiabatic conditions exist after the first few hours of occupancy. Therefore the simplified method of Chapter IV could be used for a quick approximation of the ventilation rates required. A somewhat more precise determination could be made using Case 1 solution since, in this case, any sensible heat loads in addition to the metabolic load can be included in the Q_g' term in Equation 5.5.

Reference 23 presents a method of determining minimum ventilation rates for above-ground shelters which is basically an iterative solution. It has been checked against test results for simulated occupancy studies and has been shown to predict minimum ventilation rates with a reasonable degree of accuracy. Predicted rates

have been in the range of 1 to 2 cfm/person higher than the actual rate required. The method predicts only the minimum ventilation capacity required for critical summer conditions and will consistently overestimate the requirements for cold weather ventilation. However the occupants of a shelter can decrease the ventilation rate as the conditions dictate. This method is the simplified method discussed on page 4-15.

PRACTICE PROBLEMS

5.1 A shelter is supplied with fresh air at 86°F db and 73°F wb at a rate of 15 cfm per person. The sensible heat gain from lights and mechanical equipment is 20 Btuh per person. Determine the effective temperature in the shelter if there is no conduction heat loss to the surroundings.

5.2 A shelter 10' x 100' x 8' has 100 occupants with an average metabolic rate of 400 Btuh per person. It is located underground in clay soil at an average temperature of 55°F. The thermal diffusivity is 0.017 and the thermal conductivity is 0.66. Determine the effective temperature after 24 hours of "buttoned up" operation using a cylindrical model.

5.3 For a shelter in Problem 5.2, what would be the effective temperature after 14 days if the ventilation rate were 5 cfm per person and 20 Btuh per person were added by lights and mechanical equipment. The average condition of the ventilation air is 87°F dry-bulb and 75°F wet-bulb.

5.4 An underground shelter is 25' x 20' x 8' and is ventilated at the rate of 10 cfm per person with fresh air having an average dry-bulb temperature of 84°F and an average dew point of 72°F. There are 50 occupants with an average metabolic rate of 400 Btuh per person and the equipment load is 30 Btuh per person. The initial ground temperature is 68°F and the diffusivity is 0.018 ft^2/hr. The thermal conductivity is 0.7 Btu/(hr)(ft)(°F). The surface heat transfer coefficient is 1.5 Btu/(hr)(ft^2)(°F). Using a plane wall model and a Case 3 solution, determine the effective temperature at the end of 7 days.

CHAPTER VI

MECHANICAL COOLING

The discussion in the preceding chapters has been concerned with control of the thermal environment by means of ventilation only. In many shelters this can probably be accomplished but there are situations where some form of supplemental cooling will be necessary.

The question of when to provide supplemental cooling capability is one which does not have a simple answer. It can be said that some form of cooling should be supplied wherever the financial considerations permit. This, however, does not answer the question of when mechanical cooling is justified as a matter of survival, even at the expense of some other aspect of the shelter design. In other words, when is a supplemental cooling system absolutely essential?

Any time that ventilation alone will not be sufficient to maintain the desired conditions in the shelter it will be necessary to provide supplemental cooling. Thus, a combination of high ambient temperature and humidity, combined with inadequate earth conduction effect, would be one condition where ventilation alone might not suffice to maintain a tolerable thermal environment. Inadequate earth conduction effect might mean (1) high earth temperature, (2) low conductivity, (3) insufficient wall surface area or (4) an aboveground shelter.

Another possiblity might be that the high rates of ventilation necessary would require large intake openings which would be difficult to shield from fallout radiation. If the shielding integrity of the shelter would be reduced by providing these openings, it would be necessary to reduce the size of the ventilation inlet and resort to some form of mechanical cooling to maintain the desired environment.

It is also possible that high ventilation rates could result in increased equipment costs for larger blowers and motors, ductwork, dampers, grilles, etc., to the extent that it would be cheaper to provide for a smaller capacity and add supplemental cooling. Only a detailed cost analysis will show the point at which this might occur but as a general rule of thumb, the possibility

should be considered if the calculated ventilation rate exceeds 20 cfm per person.

Even though the probability of buttoned-up operation is low, it is likely that the thermal environment cannot be controlled within acceptable limits without some means of mechanical cooling. A Case 2 analysis, as outlined in Chapter V, will show whether the possibility exists. In any case it would be desirable to consider providing a cooling system in any shelter which is to have button-up capability since the simple Case 2 analysis does not include at least two factors which might affect this condition of shelter operation. The first of these is the heat produced by equipment for generating oxygen and absorbing CO_2 which will probably be necessary to control the chemical composition of the air. The second factor is that button-up operation will most likely be necessary due to mass fires which could produce extremely high intake air temperatures and high carbon monoxide concentrations. The heat from these fires could cause a rise in ceiling temperatures in the shelter which would make the assumptions for the Case 2 analysis invalid.

Another possibility would be where analysis shows that the capacity of the shelter could be increased by providing some form of mechanical cooling. In many cases the number of occupants will be limited by the thermal environment rather than space and it is possible to increase the number if a cooling system is installed and thereby actually reduce the per capita cost of the system. In this regard it should be kept in mind that the number of persons who seek to use the shelter at the time of an attack may exceed the number for which the shelter was designed. This is especially true if the attack comes before the shelter development program has had time to create the total number of shelter spaces needed. A cooling system would help to provide some capability for overcrowding which might be worth the additional cost.

In general it can be said that there are many conditions which might justify inclusion of some form of mechanical cooling in the environmental control system. Whether or not it will be included is a matter of engineering judgment based on a thermal analysis and the cost-effectiveness factors. It also involves the degree of calculated risk which appears to be acceptable.

Assuming that a system for cooling or dehumidifying is to be installed, there are several possible methods to be considered. These might include:

1. Dehumidification by means fo a chemical desiccant or absorbent, or by mechanical means;

2. Evaporative cooling;

3. Cooling with well water;

4. Mechanical air conditioners.

At the present time it is probably not worthwhile to consider the more exotic methods of cooling, such as thermoelectric devices, since they have not been developed to the point where they are of practical value from the standpoint of cost, capacity or reliability.

Dehumidification: Since a large part of the problem in controlling the thermal environment of fallout shelters is associated with high humidity, the use of dehumidifiers has been considered as a means of reducing humidity. A brief consideration of the thermodynamic processes involved will show that this is not a practical solution to the problem.

If the desiccating device is to be wholly contained within the shelter, the so-called "black box" method of analysis may be used. In this method, the details of construction and operation of the device are ignored and only the overall energy balance is considered. Thus the analysis will apply to any form of device which removes moisture from the air.

As an example, consider the case of shelter air at an initial state of dry-bulb temperature and dew point. For one pound of dry air with its associated moisture there would be specific enthalpy, h_1 Btu/lb dry air. A dehumidification device is allowed to operate for the length of time necessary to remove some of the moisture from the air, thus reducing the dew point. It is assumed that the device is wholly contained within the shelter and has no capacity for storing energy within itself. Under these conditions no energy will enter or leave the shelter air and, consequently, there will be no change in the enthalpy. Thus the process line from the initial to the final state follows a constant enthalpy line on the psychrometric chart.

This process is illustrated in Figure 6.1 where the process is plotted on the psychrometric chart of Figure 3.1. State 1 is shown at 85°F db and 75°F dp and State 2 at a dew point of 72°F. Note that the process line slopes downward to the right, following a constant enthalpy of 41 Btu per lb dry air. The relative humidity has decreased from about 72% to just over 50% but the dry-bulb temperature has risen from 85°F to 93°F. The net result has been that the effective temperature has increased from about 80.5°F to about 83.5°F. Thus the conditions in the shelter are worse rather than better.

An examination of Figure 6.1 will show that any dehumidification process, following a line of constant enthalpy, will result in an increase in effective temperature.

It has been assumed that no energy input was required to operate the dehumidification device which, of course, would not be true in the actual case since the moisture in the air will not condense spontaneously. Thus the energy required must be put into the device (as, for example, the electric energy to operate a refrigeration machine), or it must be stored in the device (as stored chemical energy for chemical desiccants). In either case this energy will become part of the shelter system, since it was assumed it would not be stored in the dehumidifier. Therefore the drying process will result in an increase in enthalpy and the effective temperature will be increased more than was indicated for the constant enthalpy process.

During the dehumidifying process the moisture which is removed condenses and gives up its latent heat of vaporization. This latent heat becomes sensible heat in that it raises the dry-bulb temperature of the air. Thus it can be concluded that, in order for dehumidification to be an effective method of reducing the effective temperature, the latent heat given up by the condensing moisture must be removed from the shelter.

Evaporative Cooling: If dehumidifying tends to increase the effective temperature of the shelter air, it follows that increasing the moisture content of the air would tend to reduce the effective temperature. This is true, provided that the energy to supply the latent heat of vaporization comes from inside the shelter.

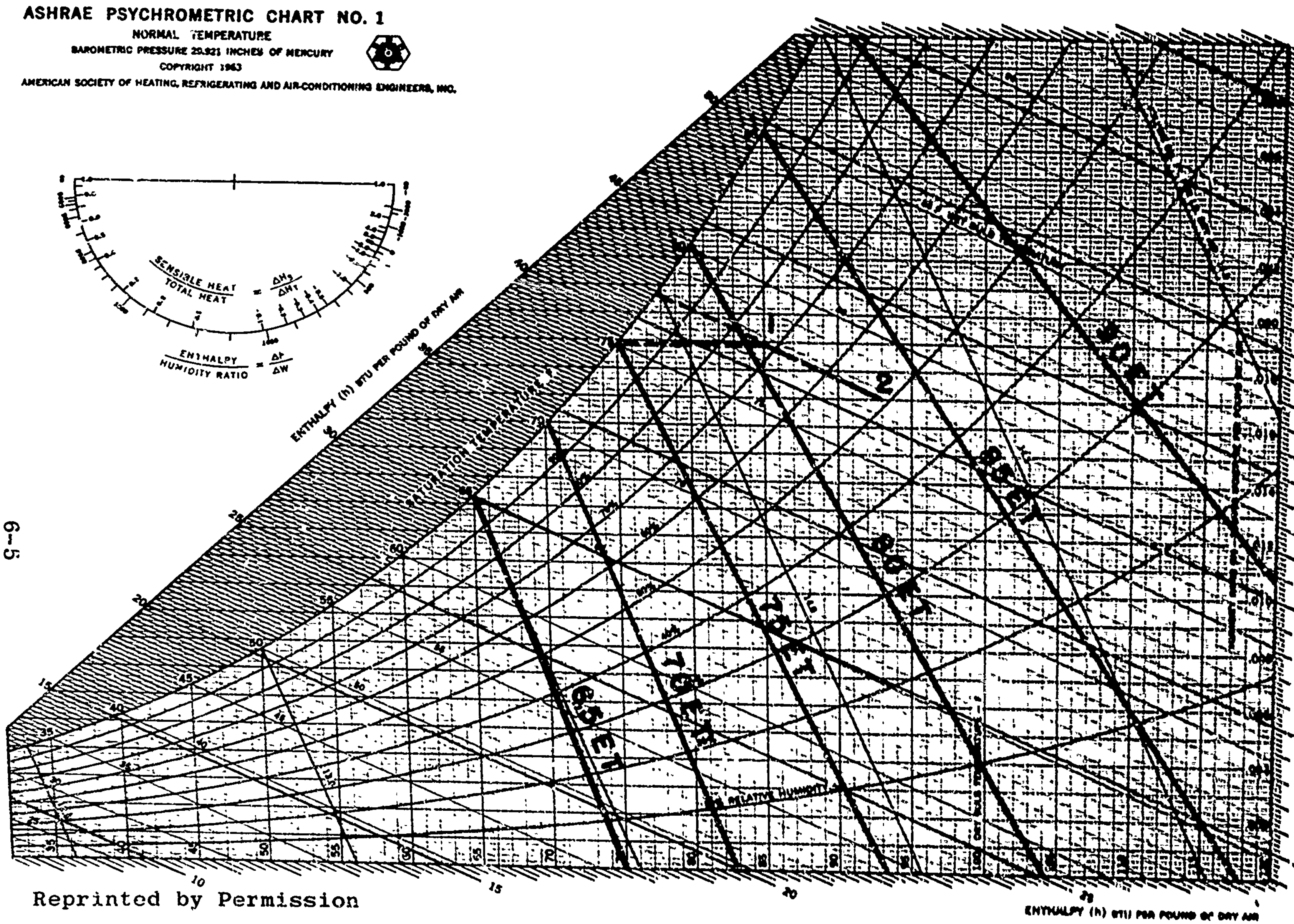


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FIGURE 6.1
DEHUMIDIFICATION OF MOIST AIR

If this energy is supplied by the surroundings the energy content of the shelter will be increased with a consequent increase in effective temperature.

The process involved in evaporative cooling is the reverse of the dehumidifying process and could be illustrated in Figure 6.1 by starting at state 2 and proceeding to state 1. Again it is assumed that no energy is transferred to or from the surroundings. Thus the evaporative process is one in which the dry-bulb temperature will decrease while the dew point temperature increases and the wet-bulb temperature remains essentially constant.

A pound of air can pick up only a limited amount of moisture. For example the air at state 2 in Figure 6.1 could be cooled to a temperature of about 77.5°F before it becomes saturated. During the process it would pick up moisture equal to the change in humidity ratio. This would be, from the figure, 0.0204-0.017, or 0.0034 lb of moisture per lb of dry air. Table 3.6 shows that a temperature of 85°F (the approximate average dry-bulb temperature for this process) the average sedentary man will evaporate 0.223 lb/hr of moisture. It would require 0.223/0.0034 = 65.6 lb/hr of air to pick up this moisture. At a specific volume of about 14.2 cu ft/lb (from the chart) this is (14.2) (65.6) = 932 cu ft/hr or 15.5 cfm to pick up the moisture for one man. If, now the moisture is added by evaporative cooling, the air no longer has the capacity to absorb the moisture produced by the man. The man's body, however, has the ability to evaporate the moisture since his skin temperature will be above the temperature of the air. Therefore, the moisture will be put into the air causing the air temperature to increase along the 100% relative humidity curve, and increasing the effective temperature.

Thus it can be seen that evaporative cooling would be limited in its effectiveness. This is not to say, however, that it can never be used effectively. There are areas in the United States, principally in the Southwest, where the normal atmospheric air conditions are hot and dry. Supply air with a very low relative humidity may make evaporative cooling feasible for reducing the shelter dry-bulb temperature, at the expense of increased ventilation rates. As pointed out in the example, any moisture which is added by evaporative cooling reduces the capacity of the air to

absorb the metabolic latent heat. Thus additional ventilation air will be necessary, For a shelter with manually operated blowers this increase in ventilation rate may increase the power requirements beyond the muscular capacity of the occupants.

The conclusion is that evaporative cooling may be used in some localities and should probably be considered as a possibility in the preliminary design. But the conditions with regard to increased ventilation rates and power requirements should be carefully analyzed before it is selected as the most desirable method of cooling.

Cooling With Well Water: The possibility of dissipating the heat generated in fallout shelters by the use of ground water from non-thermal wells* is worth serious consideration. In fact many shelter designers would consider a water well one of the most useful facilities which could be installed in a shelter, since a reliable supply of water is useful for many purposes including drinking and food preparation (if the water is potable), sanitation, fire fighting, and decontamination, as well as heat dissipation.

Ground water can probably be located at most locations in the United States and obtained from wells of reasonable depth. Figure 6.2 indicates the approximate temperatures of water which might be expected from non-thermal wells at various locations.

In order to dissipate the heat from the shelter it is necessary to transfer the heat from the shelter air to the water and then discharge the water outside of the shelter enclosure. It is necessary, therefore, to have some method of pumping the water from the well to the shelter and a method of circulating the shelter air to bring it in contact with the cooling water. The most effective method is to pump the water through a coil suspended in the shelter area and provide a fan to circulate air across the coil.

By using large flows and high velocities of the cooling water in order to obtain uniform temperatures in

*A non-thermal well is one that produces water at the same temperature in winter and summer.

the coil, and by using low air velocities in order to prolong the time that the air is in contact with the cool surfaces of the coil, and by using the counter flow principle of heat transfer, it is possible for the air temperature leaving the coil to approach the temperature of the cooling water entering the coil. If, in the process, the air were cooled below its dew point temperature, moisture would be condensed from the air so it would be necessary to provide a drip pan under the coil to collect the condensate.

In tests conducted by the University of Florida (15) this method of heat dissipation was tried in a 12-person, partially buried shelter, using simulated occupants. Water was obtained from a 75 foot well equipped with a jet-type pump which delivered the water at the surface at 40 psig. The water was at 71.5°F which compares favorably with the value of 72°F predicted from Figure 6.2 for the area of Florida where the test was conducted.

The water was routed through a serpentine coil which was 13.5 inches high by 20 inches long by 5 inches deep, with a face area of 1.87 square feet. Air was forced through the coil in a counter flow pattern to the water flow by a 1/12 horsepower, propellor-type fan and left the coil at an average face velocity of 450 ft. per minute.

Ventilation air was preconditioned to follow a cycle typical for a summer day at that section of Florida and was supplied to the shelter, by an external fan, at a rate of 3 cfm per occupant. The 12 simulated occupants (simocs) were set to deliver 200 Btuh of sensible heat and 200 Btuh of latent heat.

At the start of the test, the dry-bulb temperature in the shelter was 81°F, the relative humidity was 87% and the effective temperature was 79°FET. Water entered the coil at 71.5°F at a rate of 1915 pounds per hour and left the coil at 74.86°F. This represented a heat absorption of 6440 Btuh while the 12 simocs added 4800 Btuh.

At the end of 48 hours conditions in the shelter appeared to have stabilized at 79°F dry-bulb and 88% relative humidity, giving an effective temperature of 77.5°FET. During this time, 76.6 pounds of condensate were collected from the coil, which represented 73% of the water evaporated by the simocs.

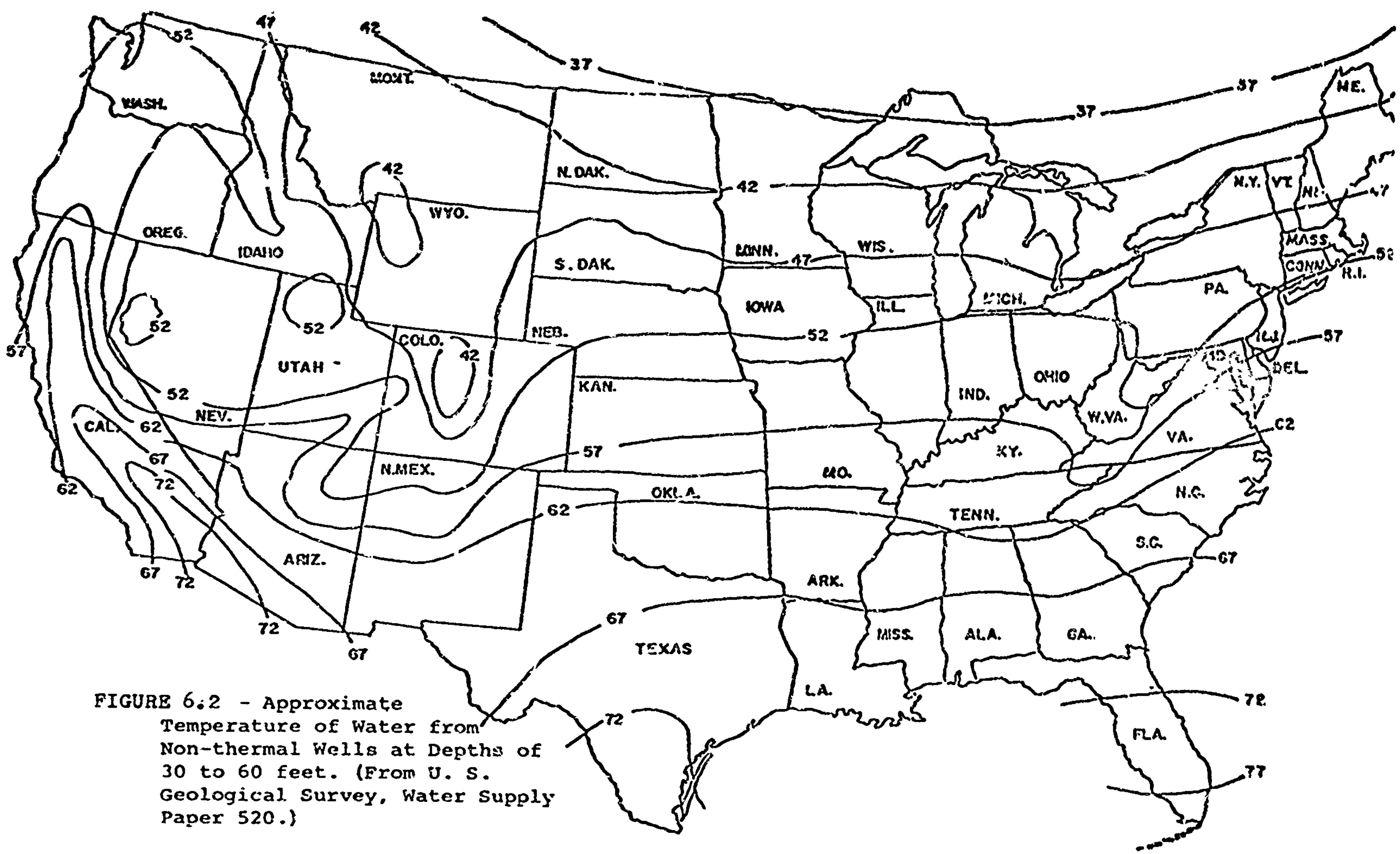

FIGURE 6.2 - Approximate Temperature of Water from Non-thermal Wells at Depths of 30 to 60 feet. (From U. S. Geological Survey, Water Supply Paper 520.)

In order to determine the effect of the water coil, the results may be compared with a test of the same shelter, with the same ventilation rate and the same preconditioned supply air, but without the coil. In this case the shelter dry-bulb temperature was 90.5°F and the relative humidity was 92 percent. The effective temperature was 88.5°FET. Thus the coil lowered the effective temperature by eleven degrees.

The power consumption to operate the coil was 1/12 hp for the fan and 1/3 hp for the pump or a total of 5/12 hp. The water flow rate of 1915 pounds per hour represents an average flow of 3.83 gallons per minute.

A similar test was conducted in a 100 occupant shelter using a larger coil and fan and a greater amount of ground water. This test was not as successful since the coil appears to have been undersized for the load imposed upon it. However it was found that the supply water at 72.2°F absorbed 3.45 Btu per pound as compared with 3.36 Btu per pound in the first test. The power consumption was 0.83 horsepower for 20,700 Btuh of cooling effect in the second test as compared to 0.42 horsepower for 6440 Btuh of cooling in the first test. Thus the second test shows 25,000 Btuh per horsepower as compared to 15,400 Btu per horsepower in the first test.

It was estimated, in the second test, that it would be necessary to double the size of the coil which was 35 inches wide by 18 inches high by 9 inches deep with a face area of 4.25 square feet. If a second unit were added similar to the first the power consumption would be about 1.7 horsepower. In order to obtain the same heat removal by electrically driven, compression refrigeration it would require about 3.5 horsepower to drive the compressor alone plus about 0.8 horsepower for the blower drives to circulate air across the condenser and evaporator coils. Thus the compression refrigeration system would require about 4.3 hp compared to 1.7 hp for the water coil (15).

Although firm conclusions cannot be drawn on the basis of these two tests alone, it appears that the use of ground water in a water coil offers an economical method of reducing effective temperatures in shelters. Figure 3.2 indicates that the 72°F water used in the tests is the highest ground water temperature to be expected any place in the United States, except in

extreme south Florida. Thus it may be concluded that this method of cooling would be even more effective in most other locations where the lower water temperatures would provide better heat transfer characteristics in the coil.

The method is, of course, dependent on the availability of ground water and involves the cost of a well. In Florida, where the tests were conducted, it is possible to obtain water from wells 60 to 80 ft in depth. In other locations it may be necessary to go much deeper to get a dependable supply of water. The deeper wells will, of course, cost more to install and will require larger and more costly pumps which will need a source of power for operation.

The cost of a well depends on many variables including size and depth of the well, the geological formation, the type of drilling rig used, ease of access to the site, local labor conditions, and the operating methods of the contractor. It is possible, therefore, to indicate only the probable range of costs.

For rock wells not equipped with screens, the cost of drilling the well and installing the casing can be estimated at $1.50 to $2.00 per inch of diameter per foot depth to 600 ft. For greater depths the range would be from $1.50 to $3.00 per inch of diameter per foot of depth (29).

The approximate diameter required can be estimated from Table 6.1, from Reference 29.

TABLE 6.1

Pumping Rate gpm	Minimum Case Size Inches
120	6 - 8
300	8 - 10
600	10 - 12
1200	12 - 14
2000	14 - 16
3000	16 - 18

The approximate cost for the pump installation, including pump, motor and controls can be estimated from Table

6.2, also from Reference 29. The costs in this table do not include the cost for drilling and installing the casing.

TABLE 6.2

COST OF WELL-PUMP INSTALLATIONS

Horsepower of Pump	Cost of Installation
1/2	$ 225
3/4	280
1	350
1-1/2	475
2	600
3	875
4	1000
5	1200
7-1/2	1350
10	1600
15	1750
20	2200
25	2500
30	3000
40	3750
50	4200

The power required for the pump is determined by the sum of the gravitational head, the velocity head and the pressure head. Since very little power is required to move water horizontally for short distances the velocity head is negligible. Therefore the power requirement is made up of the gravitational head and the pressure head. The sum of these two terms is known as the static head.

The pump work can then be determined from:

$$W = \frac{P_2}{\rho} - \frac{P_1}{\rho} + \frac{g}{g_c}(Z_2 - Z_1) \text{ ft-lb/lb} \qquad \text{(Eq. 6.1)}$$

Where:

P_2 = discharge pressure, lb/sq ft absolute

P_1 = suction pressure, lb/sq ft absolute

ρ = density, lb/cu ft

$Z_2 - Z_1$ = total lift, ft

g = local acceleration of gravity, ft/sec^2

g_o = conversion constant, 32.174 lbm ft/lbf sec^2

The work as obtained from Equation 6.1 would be multiplied by the total mass of water pumped per unit of time to obtain the power requirement. Obviously this would have to be divided by the pump efficiency to determine the power input required. The efficiency will vary with pumping conditions and must be determined from the efficiency curve for the pump selected.

The pressure head for the pump will depend on the pressure required for the cooling water system. Most public water supply systems have a delivery pressure of from 20 to 40 psi and many well pumps are supplied already equipped with storage tanks for this pressure range.

Some storage capacity for water may be desirable in the shelter installation if the water is to be used for purposes other than cooling. The cost of water storage facilities may be estimated from Table 6.3 which is also taken from Reference 29. The costs are estimated on the basis of the facilities in place and ready for use and includes valves, footing, pipe inlets and outlets and drains, all completely installed.

The total cost of a well-pump assembly, completely installed can be estimated from Figure 6.3 which has been redrawn from Reference 29. The costs include the well and casing and the pump. They do not include a water storage tank or the water coils, fan or other cooling components.

The quantity of water required for cooling purposes will, of course, vary with the ground water and ambient temperatures. Reference 29 estimates a demand of 0.1 to 0.15 gallons per minute per person to maintain an effective temperature of 85° FET. University of Florida tests showed a rate of about 0.319 gpm per person in the 12-occupant shelter, but this maintained a 77.5° FET. In the 100-occupant shelter the University of Florida test showed

TABLE 6.3

APPROXIMATE COST OF WATER STORAGE FACILITIES

Amount of Storage gallons	Pressure	Pneumatic	Elevated
500	$ 90	$ 360	---
750	135	510	---
1,000	160	630	---
1,500	245	750	---
2,500	400	1,200	---
5,000	900	2,300	3,000
7,500	1,200	3,000	4,200
10,000	1,600	4,000	5,200
15,000	1,950	4,800	10,000
20,000	2,800	6,000	12,000
25,000	3,750	7,500	13,500
30,000	4,800	---	18,000
40,000	7,200	---	21,000
50,000	10,000	---	26,000
60,000	13,200	---	35,000
75,000	19,500	---	42,000
100,000	28,000	---	48,000

a rate of about 0.12 gpm per person and the effective temperature in the shelter after 48 hours was 84°FET (15). This tends to confirm Pamero's estimate.

If a well-water cooling system is installed it will be necessary to provide some means of disposal of the water. There are several possible methods which might be considered.

1. The water may be pumped into a diffusion or recharge well in order to return it to the ground water reservoir. If the well is to be used on a day-to-day basis this is probably the best solution since it not only disposes of the water but also it helps to maintain the water table.

2. It could be pumped into an existing recharge basin. These are in use in some areas for disposal of rain water.

3. A drain field may be installed such as is used for the effluent from septic tanks.

4. The water may be discharged into existing storm or sanitary sewers.

5. The water could be pumped into a municipal water system (assuming that it is of sufficient purity) and could thus become available for use in other shelters which do not have wells.

6. The excess water could be pumped into storage facilities for post-shelter use. Such facilities would, of course, have to be developed by the community.

Water which has been used for sanitation of decontamination would have to be disposed of separately. This water could go to a covered pit and then be pumped into an existing sewer line. It could also be stored in the pit for later disposal if the pit has sufficient capacity for the entire period of shelter occupancy.

The benefits to shelter performance that might be possible, in addition to cooling capability, could be considered as part of a feasibility study in the design of new facilities. Although other sources of water may be available, such as trapped water in the building or a usable municipal system, the savings in other systems or increased capacity of the shelter may be sufficient to justify the cost of the well and pump.

1. Water for drinking, cooking and washing: With an adequate supply of well water it would not be necessary to limit the consumption of water. The physiological and psychological benefits of unlimited drinking water are difficult to assess but could be important. The hygienic benefits of having adequate water for personal cleanliness should help to reduce some of the health problems in the shelter.

2. Space utilization: The use of well water reduces the requirements for water storage facilities. Elimination of the need for

the storage containers makes the space available for other uses and could reduce the structural requirements for the floor.

3. Sanitation: An adequate supply of water permits the use of standard fixtures and systems. This should reduce costs and provide a more efficient system.

4. Fire Fighting: The control of fires in a shelter can be extremely difficult and hazardous if adequate water is not available. Hand fire extinguishers are very limited in their capacity and some of them create hazards in addition to the fire. Both CO_2 and the dry chemical types extinguish by smothering the fire with carbon dioxide and should not be used in confined spaces. The carbon tetrachloride type produces a toxic gas when exposed to the heat of a fire and also should not be used in confined spaces. The chemical foam type is an effective extinguisher (except on electrical fires) but the foam residue is very difficult to clean up. It would be almost impossible to remove this residue without large quantities of water. The common soda-acid type is probably the best choice for shelter use but it has only a 2-1/2 gallon capacity. Its extinguishing action is the same as plain water. In addition this type requires annual recharging as does the foam type.

   An adequate supply of water permits the use of fire hoses with either stream or fog spray nozzles or could permit the installation of a sprinkler system.

5. Cooling: In addition to environmental control, well water can be used for cooling of engine-generator units and air conditioning condensers. This reduces the requirement for a supply of cooling air. In general water cooling is more effective than air cooling for condensers and engine cooling systems. For environmental control well water offers a predictable, constant temperature source of heat absorption which simplifies the design analysis.

6. Shelter performance: A well-water supply increases the potential of the shelter for overcrowding or extended occupancy.

MECHANICAL AIR CONDITIONING: The most positive control over the thermal environment in the shelter can be attained by use of a mechanical air-conditioning system. Within the cooling capacity of the system the shelter occupants can have almost complete control over the conditions within the shelter and vary them to suit their needs. While a mechanical air-conditioning system may well be the most expensive type of cooling system which might be installed, and have the greatest power demand, there are some situations where it can be justified. In some shelters where well water is not available in sufficient quantity it may be the only means of providing the necessary cooling capability. In emergency operating centers or in strategically sensitive military shelters it can often be justified as necessary for the operating efficiency of the personnel or for the protection of important machines and equipment.

Once the analysis has been made and the decision reached to install mechanical air-conditioning equipment, there is a multiplicity of possible commercial units from which the selection may be made. It is probable that it will be most desirable to select from standard units, rather than specially designed components, since the standard units offer the cost savings of mass production methods.

The most common method of securing a refrigeration effect is the vapor-compression system. The usual method of driving the compressor for this type of system is an electric motor. The compressor may be of the reciprocating type, rotary or centrifugal, depending on the required capacity and the type of refrigerant used. The type of refrigerant will determine the required suction and head pressures on the compressors.

The condenser may be air cooled, water cooled or of the evaporative type. In the evaporative condenser, cooling is accomplished by air passing over the wetted surfaces of the condenser tubes. The principal cooling effect comes from the evaporation of the water from the wetted surface. If the condenser is air cooled an adequate supply of cooling air is necessary while the water cooled type requires a supply of cooling water.

The air may be cooled by passing it directly across the evaporator coil or the chilled water system may be used wherein water is chilled by the evaporator and pumped to coils in the conditioned space; the air is cooled by blowing it across the chilled water coil. The chilled water system may be desirable for shelter applications since the compressor, condenser and evaporator may be located outside the shelter enclosure and only the chilled water supply and return pipes penetrate the shielding barrier. If the shelter is also designed for blast protection the elimination of refrigerant lines between separated components of the cooling system would be particularly advantageous.

Most commercial air handling units deliver saturated air to the conditioned space at about 60°F dry bulb temperature. The coil and fan are designed to deliver about 400 cfm per ton* to the conditioned space. Power requirements can be estimated on the basis of about one kilowatt electrical input to the compressor per ton of cooling effect, plus about one-quarter kilowatt to operate the fans to move the air across the cooling coil and condenser. The actual power requirement will, of course, have to be determined from the specifications of the equipment selected.

The power requirement can be reduced by use of absorption type units. This eliminates the power requirement for the compressor but the need for power to operate the fans still remains. However, under emergency conditions, power for the fans may be within the muscular capability of the shelter occupants so that system may be operated independently of an external source of power.

There are two commonly used absorption systems; the ammonia system and the lithium bromide system. In the ammonia system, ammonia is used as the refrigerant and water is used as the absorbent. In the lithium bromide system, water is used as the refrigerant and the lithium bromide salt solution is the absorbent. The ammonia system can maintain lower evaporator temperatures but is somewhat less efficient than the

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*A ton of cooling is equal to a cooling effect of 12,000 Btuh.

lithium bromide system due to unavoidable evaporation of the absorbent water in the generator. Since ammonia vapor is both toxic and flammable, the lithium bromide system would probably be preferable for shelter use.

Both ammonia and lithium bromide absorption air conditioning units are commercially available in capacities of about 3 tons and larger. At the present time they are not being produced in sizes smaller than 3 tons. Most of the units are designed for heat input from the combustion of natural gas or liquified petroleum gas. Some large installations are designed for heat input to the generator from a steam coil. This would have little application for shelter use since steam will probably not be available and could not be generated economically.

An interesting system is the total energy concept which has been successfully applied in some large installations and may have some application in a large shelter. In this system an engine-generator is used to provide power for lights and other electrical equipment and the waste heat from the engine is used in an absorption air conditioning system to provide cooling. Such a system would have to be carefully analyzed and balanced since the electric power demand may be too small to create sufficient load on the engine for the waste heat to be adequate for the necessary cooling effect. However, for some more sophisticated installations it may offer some advantages.

Another variation which has been used with some success is the internal combustion engine driven air conditioning unit. In this unit a compression type air conditioning unit is used, with the compressor driven directly by an internal combustion engine. In most of the commercial units available the engine is equipped to use liquified petroleum gas as the fuel but any kind of engine fuel could be used. This system is an attempt to take advantage of the somewhat better coefficient of performance of the compression cycle, as compared to the absorption cycle, and at the same time make the system independent from a source of electric power. The most successful installations have been those where the waste heat from the engine could be used for water heating or similar application. For shelter use, this system does not have the flexibility

of an engine-generator and does not provide any electric power for lights. There may, however, be some situations where it might be considered.

With the wide variety of possible system configurations it is difficult to present any specific data on equipment costs. Reference 29 presents cost analysis data for four of the most common systems which may be used for estimation purposes and for comparative cost purposes. The reference gives detailed cost breakdowns for each system. Table 6.4, 6.5, 6.6 and 6.7 summarize these data.

Table 6.4 gives the total cost per person for an all-air ventilation system for a 100-man, 250-man and 500-man equipment package. The equipment includes ventilating and recirculating fan; engine-generator set and fuel tank; lights, conduits and controls; ducts, piping, supports and partition walls.

TABLE 6.4

COST SUMMARY FOR ALL-AIR SYSTEM

	Outside Air - cfm Per Person					
	5	10	15	20	25	30
100-man, cost/person	40.9	41.5	42.1	50.5	58.4	59.2
250-man, cost/person	24.6	25.2	25.8	26.8	31.1	32
500-man, cost/person	15.7	16.3	16.9	20.3	21	21.7

Table 6.5 gives the total cost per person for a mechanical cooling system using well water. The package includes ventilating and recirculating fan; well and water pump; well-water coil; engine-generator set and fuel tank; lights, conduits and controls; ducts, piping, supports and partition walls.

Table 6.6 gives the per capita cost for a compression-type mechanical cooling system with an air-cooled condenser. The equipment includes ventilating and recirculation fan; refrigerant compressor and air-cooled condenser; direct expansion coil; engine-generator set and fuel tank; lights, conduit and controls; ducts, piping, supports and partition walls.

TABLE 6.5

COST SUMMARY FOR WELL WATER-COOLING SYSTEM

	Tons Per Person				
	.015	.025	.035	.045	.055
100-man, cost/person	68.2	69.8	71.8	73.8	75.8
250-man, cost/person	39.1	40.7	41.8	42.8	44.3
500-man, cost/person	24.5	25.6	26.5	27.2	27.9

TABLE 6.6

COST SUMMARY FOR COMPRESSION COOLING SYSTEM WITH AIR-COOLED CONDENSER

	Tons Per Person				
	.015	.025	.035	.045	.055
100-man, cost/person	63.3	68.7	70.8	81.2	81.8
250-man, cost/person	36.8	41.8	45	46	52.4
500-man, cost/person	24.6	28.3	31.2	34.8	38.6

Table 6.7 gives the cost summary for a compression-type mechanical cooling system with a water-cooled condenser. The equipment includes the same components as for the air-cooled condenser system except that the condenser is water-cooled and a well and pump are added.

TABLE 6.7

COST SUMMARY FOR COMPRESSION COOLING SYSTEM
WITH WATER-COOLED CONDENSER

	Tons Per Person				
	.015	.025	.035	.045	.055
100-man, cost/person	75.3	79.6	91.1	103.2	103.8
250-man, cost/person	44	45.8	51.2	54	54.3
500-man, cost/person	28.9	30.5	34.4	36	39.6

It should be emphasized that the preceding data should be used only for very generalized estimation purposes since actual costs at any given location can vary significantly from these figures. The data for well water systems are based on an assumed 200 foot depth at a construction cost of $10 per foot. Actual cost will probably differ from this. No attempt was made to credit the well water systems with the possible savings which could be realized from the other capabilities possible with the well-water supply.

An examination of the data reveals an interesting possibility. In Table 6.6 the cost of providing 0.045 tons per person of cooling in a 250-man shelter is only one dollar per person more than for providing 0.035 tons per person. 0.035 tons is 420 Btuh of cooling effect, just about enough to remove metabolic heat and some of the heat from lights. 0.045 tons is 540 Btuh of cooling effect, which would probably provide almost comfort conditions. Thus for one dollar per person additional cost the shelter could be designed to provide conditions which are considerably better than the bare survival conditions which are usually assumed due to economic necessity.

Similar small cost increments can be found at other points in the tables, as for example, in Table 6.5 there is only a $3.40 per person increase for the entire range of capacities given for the 500-man package. Although these small incremental increases will not necessarily occur at the same points which are shown

in the tables, they are typical of the cost variations which can occur when standard units are employed. Consequently, when using mechanical cooling systems, it is often possible to design on a comfort basis, or at least moderate conditions, rather than on the basis of maximum tolerable conditions.

PRACTICE PROBLEMS

6.1 For Las Vegas, Nevada, the 5% summer climatic conditions are given in Table 5.1 as 106°F dry-bulb and 70°F wet-bulb. How much moisture must be evaporated into this air to cool it to a dry-bulb temperature of 85°F? What would be the final condition of the air? Would evaporative cooling for a shelter be desirable in this area?

6.2 Estimate the cost for a water well and pump for a 1000 occupant shelter if a rate of flow of 0.15 gpm per person is required for cooling purposes. The well must be 200 feet deep and the pump must deliver the water at the surface at 40 psig.

6.3 In a 500-man shelter at what ventilation rate does it appear that it would be less expensive to use a well water cooling system than an all air system?

6.4 For a shelter in Problem 5.2 what would be the effective temperature at the end of 14 days if a mechanical air conditioner supplied fresh air at the rate of 3 cfm per person? What capacity air conditioner would be required?

CHAPTER VII

POWER SYSTEMS

As soon as the need for mechanical systems in a protective shelter has been established, the requirement for some type of power system has been determined. Since many shelters will require mechanical systems, though they be simple or complex, it follows that these shelters will need a source of power if the mechanical systems are to be used. Power may be required for lighting, cooling, communications, or pumping in addition to the requirements for environmental control. Consequently, the well-being of the occupants of the shelter will depend directly on the capability of the power system provided.

Given sufficient money, it is not difficult for an engineer to design a power system that will provide the utmost in capacity, reliability and safety. However, as is the case with all shelter components and systems, cost limitations will necessitate some compromises with the theoretically ideal power system. The first requirement must be that the system be justified economically and come within allowable budget for the shelter. Again the designer is faced with determining the minimum system which is compatible with survival, and then providing anything in addition which can be managed within the finances which are available.

The possible sources of power for shelter use can be summarized in three main categories:

1. Existing public utility services.
2. Power produced by the muscular activities of the occupants.
3. Auxiliary power systems.

Each of these should be investigated to determine if it will supply adequate, reliable power to the shelter.

EXISTING PUBLIC UTILITY SERVICES

The most convenient source of power for a shelter would be to use existing public utilities. This would supply an essentially unlimited amount of power with no capital investment other than running the necessary service wiring.

The effects of a nuclear explosion consist of thermal radiation, initial nuclear radiation, blast and shock, and residual nuclear radiation. In addition, there are electromagnetic effects which accompany the explosion, involving an electromagnetic pulse of short duration from the explosion itself (or from the disturbed region

in its vicinity) and alterations to the electrical properties of the atmosphere due to changes in the normal ionization. The study of the electromagnetic pulse and its effects is a highly specialized field. For communications centers and similar facilities special studies and designs are necessary.

There have been several studies made of the possible effects of nuclear weapons on generating and distribution facilities (31, 32, 33). These studies are analytical in nature since there is very little experimental evidence available. The damage at Hiroshima and Nagasaki has yielded some information on the effect of low yield (15-22 KT) weapons, as have some of the atomic tests conducted in this country. However, there are no data on the effects of high yield weapons or on the effects of multiple bomb attacks. The following information is compiled from the three references cited.

The thermal radiation can cause ignition of various types of combustible materials. However, such materials are usually not common around an electric generating plant so it may be assumed that the thermal radiation will have a negligible effect on the generating facilities. The same may be said of the substations. Experience with forest fires has indicated that high voltage transmission lines, which are usually carried on steel towers, are seldom damaged by the fire. However, transmission and distribution lines carried on wooden poles could be extensively damaged by fires started by the thermal radiation.

It would require extremely high intensity of initial nuclear radiation to have any significant effect on the generating plant or distribution system. These effects would occur only in areas of high peak overpressures from the blast effect. Since the blast effects will cause the greater damage, the effect of initial nuclear radiation on the system components may be neglected.

The most severe damage to the electric utility system would come from the blast and shock effects of the nuclear explosion. Since no two generating plants are exactly alike, it is possible only to make some generalized assumptions concerning the nature of possible damage which probably would occur at various levels of overpressure. Table 7.1, which has been taken from Reference 33, summarizes these probable effects on an electric generating station.

TABLE 7.1

OVERPRESSURE-DAMAGE RELATIONSHIPS FOR ELECTRICAL POWER GENERATING STATION SUBJECTED TO THE EFFECTS OF SMALL NUCLEAR (20-30KT) WEAPONS

Item	Description of Damage	Overpressure psi
Air and Flue Gas System	Boiler, preheater, breeching ducts, economizer, and fan-housing are caved-in, interrupting the draft	2 - 3.5
Feedwater & Steam System	Debris damage to turbine control panels, condensate and boiler feed pumps, feedwater and steam piping and deaerating heater	2 - 5
Circulating Water System	Screens clogged, pumphouse and crib damaged	2 - 4
Electrical System	Meters, disconnect switches, bushings, insulators, control panels damaged by debris	2 - 5

As a generalized conclusion it may be stated that a steam electric generating plant subjected to blast overpressures of 3 psi or greater will probably be out of service and could not be put back in service without major repairs.

It is interesting to note that much of the damage would be from debris and from "missile damage" due to deformation or failure of the enclosing structure. For this reason, open air plants, which are common in the South and Southwest, could probably withstand somewhat greater overpressures than could the usual enclosed plant. However the possibility of damage to the air and flue gas systems would remain about the same.

Hydroelectric plants, by their very nature, should be able to withstand somewhat higher overpressures than can a steam plant. However the possibility of deformation or failure of aboveground structures is about the same. Consequently the possibility of debris or missile damage to the electrical system is very much the same. Structural damage to the dams and locks

probably would not occur under about 15-20 psi but building walls and roofs could fail at overpressures as low as 3-4 psi.

The possible effects of blast overpressures on internal combustion engine plants have not been as extensively investigated as have thermoelectric and hydroelectric generating facilities. The engine-generator set would probably resist overpressures almost as great as would a steam turbine-generator, but this is not the critical factor. A typical diesel generating plant is usually housed in a structure with relatively large window areas. The windows could be expected to fail at about 0.5 psi overpressure, and power production could be interrupted by flying glass. Again debris damage to the electrical system could be expected to occur at from 2 to 5 psi. Thus, it can probably be concluded that the plant would be out of service if it experienced 3 psi overpressure. It might be out of service at pressures as low as 0.5 psi, depending on the results of flying glass from broken windows.

The foregoing summary is very generalized and can be used only as an indication of what might occur. Features of construction or location of the individual plant could result in either greater of less resistance to blast effects.

The effects of blast overpressures on transmission and distribution is summarized in Table 7.2, also taken from Reference 33.

The values in Tables 7.1 and 7.2 appear to be fairly well documented for small (20-30 KT) weapons. For large weapons, it is known that the damage at any given overpressure will be greater due to the longer duration winds. It is, however, difficult to qualify

TABLE 7.2

OVERPRESSURE-DAMAGE RELATIONSHIP FOR ELECTRIC POWER TRANSMISSION AND DISTRIBUTION SYSTEM ELEMENTS SUBJECTED TO THE EFFECTS OF SMALL NUCLEAR (20-30 KT) WEAPONS

Item	Description of Damage	Overpressure psi
Transmission line (wood pole)	Poles broken, tilted, lines down	5 to 8
Transmission line (steel tower)	Towers collapsed, buckled, lines down	4 to 5
Cables, Wires	Separated from supports	3 to 6
Substations, Outdoor	Broken control instruments, batteries, etc. in metal cubicles	5 to 6
Substations, Housed	Broken control instruments and batteries (unreinforced masonry house with wood roof assumed)	3 to 4

this information. In view of the lack of specific data, it is recommended that the overpressure values in the tables be reduced to three-quarters of those shown when considering weapons in the megaton class.

It is estimated that the transmission lines would probably be down at about 4 psi; substations would be out of service at about 4 psi; and local distribution lines on wood poles would be down at about 2 psi. These local lines are usually on poles about 100 feet apart and the required clearance from other objects is less than for the high voltage transmission lines. These lines are, therefore, subject to debris damage such as falling trees (33).

The conclusions from the above summaries are that almost any generating plant would probably be out of

service after receiving blast overpressures of 3 psi or greater and that local distribution lines would be down at 2 psi or greater.

Table 7.3 shows the distance from ground zero to which overpressures of 2 psi and 3 psi would extend, based on information from Figure 3.66 in the Effects of Nuclear Weapons (3).

TABLE 7.3

RANGE TO WHICH 2 PSI AND 3 PSI PEAK OVERPRESSURE WILL EXTEND FOR SURFACE BURSTS OF VARIOUS YIELDS

	Distance From Ground Zero--Miles	
Yield	3 Psi	2 Psi
1 KT	0.38	0.47
20 KT	1.00	1.3
50 KT	1.4	1.74
100 KT	1.67	2.2
500 KT	3.00	3.8
1 MT	3.8	4.7
10 MT	8.2	10.2
20 MT	10.3	12.9
50 MT	14.0	17.4

For generating and distribution systems outside of the area affected by blast and thermal radiation the only hazard will be from the residual nuclear radiation or fallout. The radiation intensity of fallout probably will be low enough to have no effect on materials or equipment so the only consideration is the effect on personnel.

It is apparent that if power is needed in an occupied fallout shelter it will also be necessary that the operating personnel for the electric power system be

sheltered. It is also necessary that the plant can be operated by the personnel in the sheltered areas.

It is probable that most thermoelectric generating stations have areas in the plant which would provide adequate shelter from fallout. However not many plants are provided with operating and control systems which would permit the plant to be operated from these areas. In some of the newer plants this may be possible with relatively minor alterations or additions to the control systems. In most older plants it probably cannot be done without major remodeling of the system. Consequently some plants have adopted a procedure for shutting down if attack is imminent.

If the plant continues in operation during the fallout period some fallout particles would probably be taken in with the combustion air. Some of these would be deposited in air preheaters, on furnace walls, boiler tubes and flue gas passages and some would be exhausted with the flue gases. There would, therefore, be some degree of contamination of the steam generator. A sheltered location for operating personnel would be required until radioactive decay reduced dose rates to safe levels but there would be no other adverse effect on the operation of the plant. Therefore, whether or not a plant remained in operation would depend on the availability of shelter for personnel and the emergency policies and procedures adopted by the management of the particular plant.

Hydroelectric plants can be operated more easily during fallout than can steam plants. By virtue of their construction they provide excellent shelter for the personnel in most cases. Inspection tunnels in the dam, for instance, may offer a protection factor of almost 10,000. In general it is not too difficult to provide for remote or automatic operation and, in fact, some plants are already set up for automatic operation. Since air requirements are minimal there would probably be no need for shutdown during fallout. As a consequence, it is very probably that a hydroelectric plant could stay in service if it received no blast damage.

Internal combustion engine plants probably provide little in the way of fallout protection for their personnel, but such protection can be added at reasonable cost. Because of the air requirements it probably would be best to shut down during fallout, especially

in the case of a gas turbine plant. However, restarting is comparatively simple in most cases and provision for remote operation can be made at modest cost. Therefore, an IC engine plant can probably remain in service, assuming no blast damage, if some advance planning is done to provide for operation during or after fallout.

Substations will present no particular problem, assuming there is no blast damage, since their operation, in almost all cases, is automatic. Normally no personnel are required to be present; consequently, there is no reason to believe that they could not operate normally during or after fallout.

The high voltage transmission lines and the local distribution lines probably will not be affected by fallout radiation although the possibility exists that the radiation intensity could be sufficiently high so as to cause ionization of the insulation, resulting in high voltage shorts. However, there is the problem of routine maintenance, especially on the distribution lines. These lines normally require almost constant repair work due to natural occurrences such as falling trees or branches, lightning damage to transformers, burned out transformers, or broken lines due to snow or ice. Interruptions of service from such causes are common and are usually handled so as to restore service promptly. Under fallout conditions, however, repair crews could not work on the lines or could work only for a very limited time.

The power requirements for a shelter will be most critical during the summer months when excessive effective temperatures are most likely to occur. Unfortunately, this is also the time of year when thunderstorms are most prevalent, with their associated gusty winds and electrical disturbances which wreak havoc on electrical distribution lines.

From the preceding discussion, a conclusion is that electric utility power may well be available at the shelter but there is a possibility that it may not be available. The designer might, therefore, consult the owner of the facility to determine his desires in regard to the provision of auxiliary power.

GAS UTILITIES

Any analysis of the availability of public utility services should include a consideration of both natural gas and liquefied petroleum gas (LP gas) services, since gas can provide a source of energy for use in a shelter. Even though it may not be as versatile or convenient as electric power, the indications are that it may be more reliable.

Gas, as a source of energy, can be applied for shelter use in two ways. The first, and probably most versatile, method would be to use the gas as a fuel for an engine-generator. The electric output of the generator then supplies the necessary power for the shelter. Engines equipped to burn natural gas are available both in spark ignition and compression ignition types. The compression ignition engines generally use the dual fuel principle in which a mixture of gas and air is taken in on the suction stroke and a pilot charge of fuel oil is injected near the end of the compression stroke to initiate the combustion. Such engines operate with about the lowest brake specific fuel consumption (bsfc) of any internal combustion engine. LP gas engines are readily available in almost all sizes since they are all converted gasoline engines.

A natural gas engine would eliminate the necessity of storing a supply of fuel in or near the shelter since the fuel would be taken from the pipe line as needed, provided there was reasonable assurance that the supply would not be interrupted. If a dual fuel engine were used, it would, of course, be necessary to store a supply of fuel oil for the pilot fuel.

Fuel for LP gas engines would be stored in tanks outside the shelter. These tanks may be either above ground or buried and are necessarily pressure tanks. Since LP gas for engine fuel use is principally propane, the tanks will have a pressure of about 100 psi.

The second method of application would be to use the gas directly for the various shelter services such as cooling, water heating, absorption air conditioning, and even gas lights. This may be suitable for a small shelter where the ventilation blowers can be manually operated but in larger shelters it will be necessary to have power for the fans and blowers. Although it may be possible to provide some sort of gas turbine drive for these, it would probably be more simple and less expensive to go to the engine-generator application. In some cases it may be desirable to use gas for heating, cooking and air conditioning and provide a smaller engine-generator for lights and power for the ventilation blowers.

Studies of damage at Hiroshima and Nagasaki and the series of tests made in Nevada in 1955, indicate that the underground gas mains are little affected by the blast. However, there would be a serious problem of breakage in service connections even out to overpressures as low as 2 or 3 psi.

In an LP gas installation, the fuel supply is stored on the premises and would be continuously available. Since the tanks are under pressure, no pump is necessary to cause flow from the tank to the appliance or engine. In the last days of the shelter occupancy, it may be possible to receive delivery of additional supplies; fuel from tank trucks which can be filled at bulk storage plants, provided radiation levels permit. It would require only a few hours exposure of the truck driver to deliver fuel supplies to several shelters.

It may be concluded that natural gas and LP gas would offer a more reliable source of energy for a shelter than would electric power. but that the application of gas for shelter use would be more complicated and probably require more expensive equipment.

POWER FROM HUMAN MUSCULAR OUTPUT: The one source of power which will always be available in an occupied shelter is that which can be produced by the muscular effort of the occupants. The ability of humans to produce power should, therefore, be considered in relation to the power requirements of the shelter.

The amount of power which can be produced by a human being depends on age, sex, physical condition and general level of skill at the task being performed. It will also vary with psychological motivation and with environmental conditions.

The power output will depend on the portion of body muscles being used. In general, when only a small part of the muscles are used in work or exercise, the power output is small and fatigue sets in rapidly. When larger muscle masses are used the power output is greater and the effort can be continued for a longer period of time.

One of the simplest methods of utilizing muscle power is hand cranking. However, in this method only the hand, arm and shoulder muscles are used and the power output is small. The person doing the cranking will tire rapidly and the power output will decrease quickly. Since the cranking is done at chest level the person must assume a fairly rigid, uncomfortable posture and discomfort soon sets in.

The method which uses the greatest number of muscles is rowing, using a sliding seat. This is the method used in crew racing shells. In a crew race a work rate of 1140 Btuh, or about 0.45 horsepower, has been recorded. This led to exhaustion in 22 minutes (10). The complexity of the movements involved require considerable training to master the necessary level of coordination. This, plus the bulky equipment required. make it an undesirable method for shelter use.

Probably the most effective method of applying muscle power in a shelter is by pedaling. The large leg

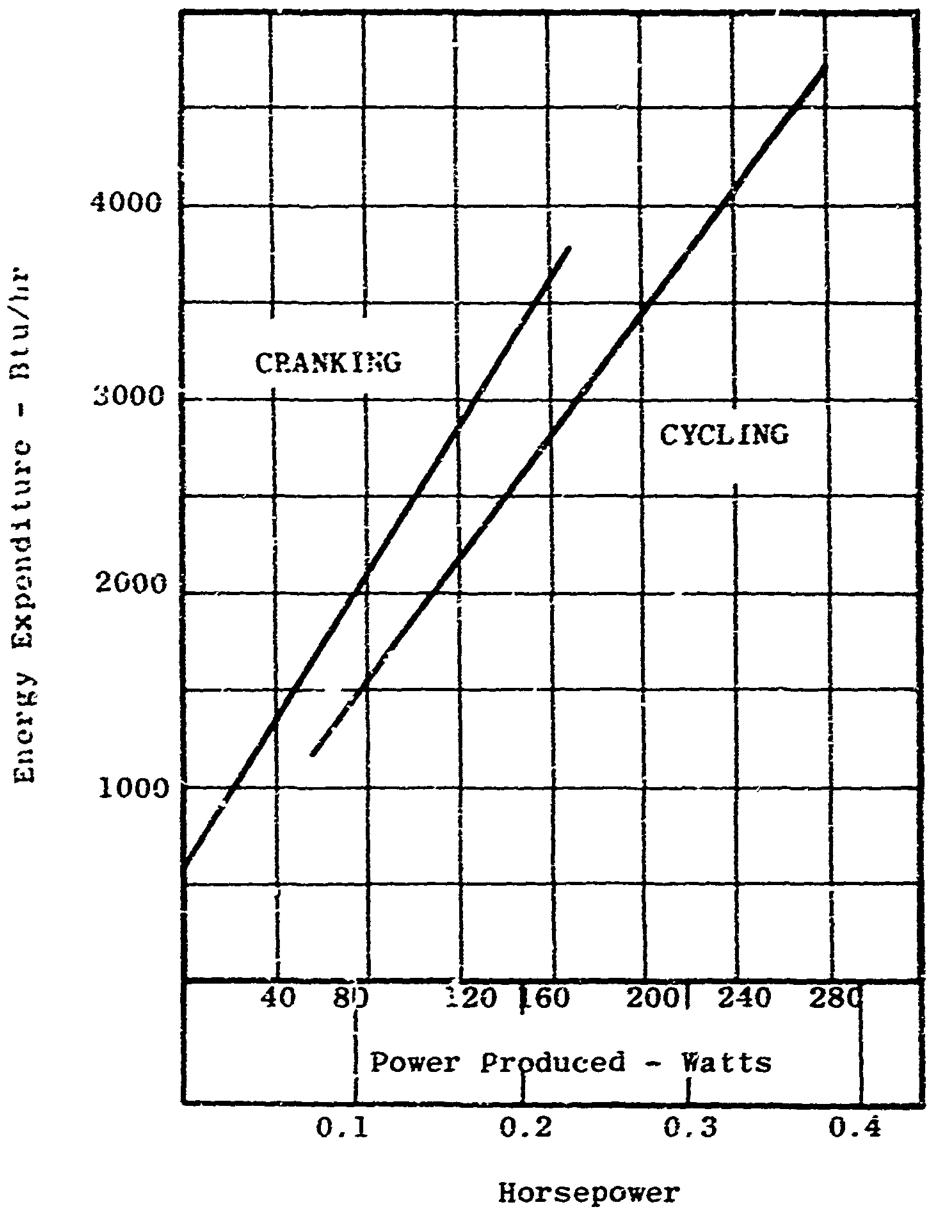


FIGURE 7.1 - Relationship Between Energy Expenditure and Work Load in Cranking and Cycling. (Abridged and Redrawn from Reference 38.)

muscles offer a more constant level of output and, since the legs are relieved of the body weight, the duration of output can be expected to be longer. An additional advantage is that most people are trained in pedaling a bicycle and can perform the task more or less automatically.

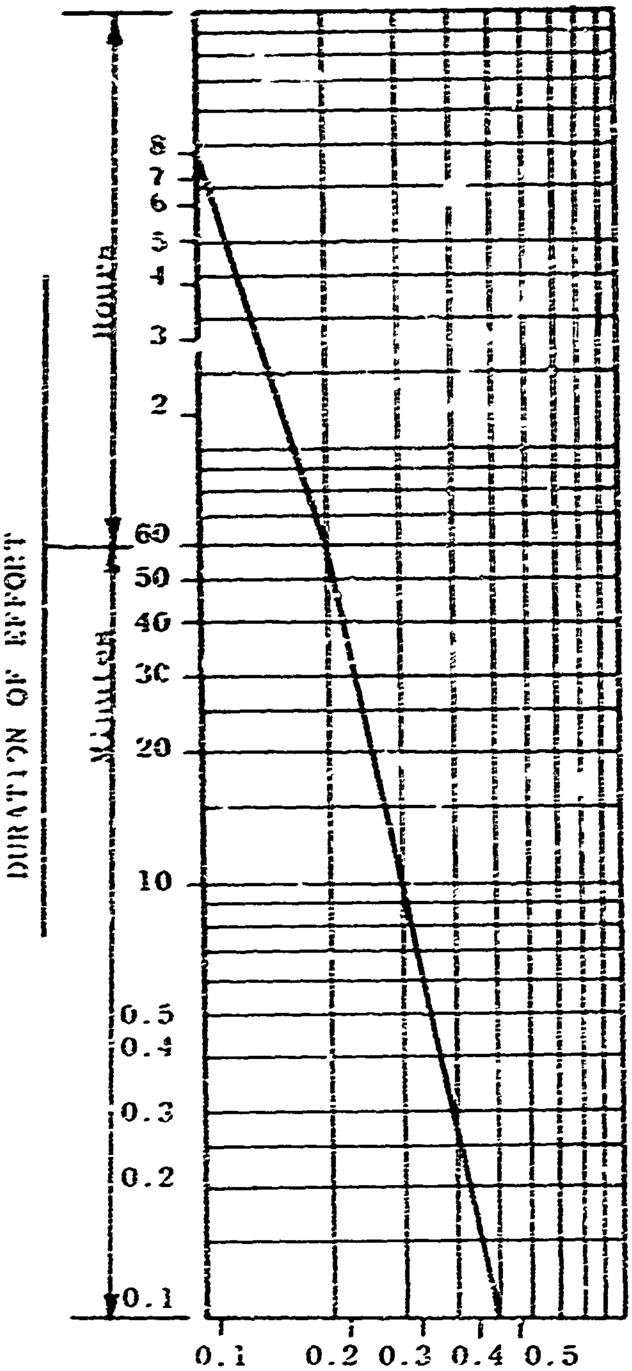
Figure 7.1 shows the relationship between power output and energy expenditure for cranking and pedaling, the two most common methods of utilizing muscular energy. It can be seen from the chart that a given energy expenditure will result in a greater power output by cycling than by cranking. Conversely, a given power output can be attained with less expenditure of energy by pedaling.

Figure 7.2 shows the the maximum work capacities for fit young men. As the power output increases the length of time for which the effort can be sustained decreases rapidly. A power output of 0.1 horsepower can be sustained for about 8 hours, but an output of 0.2 horsepower can be sustained for only about 40 minutes.

The curve shows the work capacity for young men who are physically fit. The average person probably cannot sustain an output of more than about half of the values given. Reference 38 states that 0.10 horsepower can probably be sustained for 3 to 4 hours by a large proportion of the individuals in a shelter: i.e., females of average physical fitness from 13 to 50 years of age, and males of fair or better physical fitness from 10 to 50 years of age. If a device requires an input of 0.15 hp it could be used, for sustained periods, only by males between 16 and 30 years of average or better fitness.

It should be noted that the metabolic rate of the person doing the work increases sharply From Figure 7.1 the energy expenditure for an output of 0.1 hp is about 1500 Btuh for the cycling operation and approximately 1900 Btuh for the cranking operation. Thus the person working on a manually operated blower will produce 4 to 5 times the metabolic heat of the average sedentary occupant.

If it is assumed that half of the shelter occupants would be capable of producing one-tenth horsepower for



Horsepower
(if 20% efficient)

Figure 7.2 - Suggested Maximum work capacities of fit young men (Redrawn from Reference 38).

a period of 3 to 4 hours it is possible to determine the power available from the occupants of a shelter. This power is, of course, input power to the shaft of the device being operated. The output power available will depend on the efficiency of the device.

A theoretical calculation is given for the horsepower required to move a cubic foot of air against a resistance of 0.1 inch of water, assuming a fan efficiency of 100 percent.

$$hp = \frac{(62.4 \text{ lb/cu ft})(1 \text{ cfm})(0.1 \text{ in})}{(12 \text{ in/ft})(33{,}000 \text{ ft lb/hp - min})} = 0.00001573 \qquad \text{(Eq. 7.1)}$$

The efficiency of the fan depends on the shape of the fan blade, and upon the speed of the blade tip. The best efficiency that can be expected from fans operated at design speed falls in the range of 70 to 80 percent. This relatively high efficiency occurs when the fan is delivering from 40 to 60 percent of its maximum capacity, and if the capacity of the fan is increased by increasing the speed of the fan blade, the efficiency falls quite rapidly. For a forward curved blade operating at 80 percent capacity, an efficiency of 20 percent might be expected. If a plentiful supply of electricity is available, it is only necessary to oversize the fan motor in order to increase air flow, with the only penalty being an increase in power consumption. Therefore, it is not uncommon to find a major portion of fans in commercial applications operating in the range of 20 percent efficiency.

For fallout shelter use, where there may be limited power available, and especially if the fans are to be driven by the muscular activity of the occupants, this practice should be avoided. Fans should be selected and sized to operate at maximum efficiency in order to conserve the energy of the occupants. This would mean that in most cases fans would deliver 40 to 60 percent of rated air delivery capacity, but would operate at 70 to 80 percent efficiency.

EXAMPLE 7.1: Determine the horsepower input required for a manually operated fan for a 100 occupant shelter with a ventilation rate of 20 cfm per occupant, if the fan efficiency is 70%. The fan must overcome a resistance of 0.25 inch of water.

SOLUTION: From Equation 7.1 the horsepower required is 0.00001573 hp per cfm per inch of water. Therefore:

$$hp = \frac{(100)(20)(0.00001573)(2.5)}{0.70} = 0.1125 \text{ hp}$$

If one-half of the occupants could produce 0.1 hp each for a 3 hour period, the power requirement appears to be within the capabilities of the occupants.

A single one-man VK can supply the necessary 2000 cfm if the equivalent length of duct is 200 ft. This is due to the fact that 200 ft of 20-inch round duct has a friction loss, or resistance, of only about 0.12 inches of water whereas the example was computed for 0.25 inch of water.

The power required to operate a pump for well-water cooling can be estimated from the following equation, assuming that 0.15 gpm per person is required.

$$hp = \frac{(0.15 \text{ gpm})(8.33 \text{ lb/gal})}{33000 \text{ ft-lb/hp-min}} = 0.0000379 \text{ hp per person per ft of head} \qquad \text{(Eq. 7.2)}$$

The head will consist of the gravity head, depending on the depth of the well, plus the equivalent head of the pressure loss through the piping and coil. If a total head of 100 feet is assumed, the power requirement for a 100 occupant shelter will be 0.379 hp for a pump with 100 percent efficiency. If a positive displacement pump with an efficiency of 50 percent is used, the power input becomes 0.758 hp. This would require the combined effort of 8 persons.

It would still be necessary to operate a fan to supply ventilation air and to move it across the coil. If a minimum ventilation rate of 3 cfm per person is assumed and the water coil adds ¼ inch of water to the resistance, the required horsepower is:

$$hp = \frac{(3)(100)(.00001573)(2.5)}{0.70} = 0.017 \text{ hp}$$

if a fan efficiency of 70% is assumed.

The total power requirement is thus 0.775 hp which would require a mechanical or electrical power source. There is no manually operated device available which would permit the simultaneous input from eight persons.

Other than the VK units and a few types of small, hand-cranked blowers, manually operated devices to meet the requirements for shelters are not available. Generally it would not be feasible to design and fabricate a special system for a specific facility.

AUXILIARY POWER SYSTEMS: The previous discussion has indicated that it might be desirable to provide an auxiliary power system for many shelters. It is necessary, then, to consider the various types of systems which are available in order to determine which would be most suitable for use in the shelter.

The possible systems which might be considered are:

1. Storage batteries
2. Internal Combustion Engines
3. Gas Turbines
4. Steam Engines or Turbines

There are many other power producing devices which might be considered, such as solar cells, thermoelectric devices, fuel cells, magnetohydrodynamic (MHD) generators, thermionic generators, and nuclear power. These may be eliminated from consideration, at the present time, since they have not yet been developed to the stage where they are competitive with more conventional power generators in terms of cost, efficiency or reliability. Of those mentioned, the fuel cell has probably been developed to the greatest extent and is very close to being competitive with internal combustion engines in cost and exceeds them in efficiency. However they are not yet reliable enough to merit serious consideration for shelter use, although this could change within a few years.

In considering an auxiliary power system for shelter use, some of the factors which must be taken into account, not necessarily in order of importance, are listed below:

1. Availability
2. First cost
3. Operating cost

4. Reliability
5. Ease of starting and operating
6. Maintenance requirements
7. Storage characteristics
8. Safety
9. Air and water requirements
10. Auxiliary equipment required
11. Space requirements

A brief review of these criteria would tend to indicate that steam engines and turbines could be eliminated on the basis of the large amount of auxiliary equipment needed (boiler, pumps, condenser), the space required for this equipment, the high first cost, the large amounts of water required (about 40 pounds of condenser cooling water for each pound of steam), the large amounts of combustion air required, and the fact that trained personnel are required to operate a steam plant. In addition, it is generally considered that, for capacities less than about 5000 kw, a steam plant is less efficient than a diesel generating plant.

Storage batteries can be eliminated on the basis of high first cost, the need for auxiliary battery charging equipment, large space requirements for a given capacity, poor storage characteristics, and the fact that the acid used as the electrolyte constitutes a safety hazard, as do the explosive fumes produced during the recharging process. However, it would probably be desirable to have batteries available, perhaps of the so-called dry-charge type, for starting the auxiliary power system and for emergency lighting. It would also be desirable to have a supply of dry-cell batteries for flashlights and lanterns. These would have to be replaced at least once a year during the standby period since they have a very short shelf life.

This, then, leaves internal combustion engines and gas turbines to be considered as the prime mover for the power system. These may be considered under three main headings; compression ignition engines, spark ignition engines, and gas turbines.

<u>COMPRESSION IGNITION ENGINES</u>: Compression ignition engines, commonly referred to as diesel engines, are available in many different forms: air cooled or water cooled, two cycle and four cycle, naturally aspirated, supercharged, or turbocharged. They are

generally low-speed, heavy-duty engines, relatively large and heavy for their power output. They operate either on No. 1 or No. 2 fuel oil or, in the dual fuel type previously mentioned, on natural gas. (The dual fuel engines are not readily available in the smaller sizes and, therefore, should be considered only for very large shelters.) They are built in very large sizes, but only the sizes of 500 hp or less will be considered here.

Reference 41 lists the power ranges of industrial diesel engines, operating at rated speeds from 1200 to 2400 rpm, as follows:

Two cycle, water-cooled, supercharged	33-500 hp
Two cycle, water-cooled, turbocharged	140-500 hp
Four cycle, air-cooled, naturally aspirated	6-23 hp
Four cycle, water-cooled, naturally aspirated	4-500 hp
Four cycle, water-cooled, turbocharged	70-500 hp

Diesel engine-generator sets are available in power ratings from 1 kw up, although they are not produced in quantity as are engine-generator sets using spark ignition engines. The cost of a 1 kw unit is approximately $1,000, but the price per kilowatt decreases for larger sizes. At 5 kw the price is about $300/kw for an air-cooled diesel-generator set.

Diesel engines normally provide rugged, reliable, economical service but are quite sensitive to variations in intake air temperature and pressure. An increase in temperature and/or a decrease in pressure will cause a reduction in density of the air, resulting in a decreased mass of air being taken in on the suction stroke. The decreased air limits the amount of fuel which can be burned and causes a decrease in power. A naturally aspirated engine is also quite sensitive to exhaust back pressure, especially the two-cycle model. Supercharged and turbocharged models are relatively unaffected by exhaust pressure.

Because of their higher compression ratio and more massive components, diesel engines are somewhat harder to start than spark ignition engines, especially in cold weather when the fuel oil does not vaporize readily. However they can be started with standard battery-operated starting mechanisms. In cold weather they are often primed with a small amount of highly volatile fuel, such as ether, for starting purposes. Engines up to about 5 hp can probably be started manually with a rope starter. Larger engines would require some sort of energy storage system for manual starting.

Compression ignition engines offer some advantages from the standpoint of safety. The fuel is not highly flammable and does not vaporize at normal atmospheric temperatures so that the danger from fire or explosion is negligible. The exhaust fumes from the engine are objectionable from the standpoint of odor but have a lower CO content than those from gasoline engines.

Since any engine-generator set for auxiliary power service must stand idle for long periods of time the storage characteristics are important. For shelter use the storage period is usually taken as ten years, to be followed by two weeks of continuous operation. The equipment must be capable of sitting idle for long periods of time and still be readily started and operated when needed.

Any engine is susceptible to rust, corrosion, rotting and mold when it is sitting idle. In addition there would be fouling due to gum, sludge and sedimentation from fuels and lubricants stored in the engine and loss of liquids due to leakage or evaporation. A further problem is the deterioration of fuels during storage.

It is necessary to set up a maintenance procedure during the storage period to insure that the power system will be ready when it is needed. In general this will mean "exercising" the engine at frequent intervals and replacement of the stored fuel as needed.

The compression ignition engine is somewhat less vulnerable to the formation of gum and sludge in the fuel since the fuel filter will remove it before it reaches the injectors. However, the injectors will clog very easily if the impurities pass the filter. In fact,

the injectors are the most likely source of trouble in the engine. If they should become clogged the only remedy, under shelter conditions, would be to replace them. Consequently a spare set of injectors should be provided, along with the instruction manual for the engine and the necessary tools.

Fuel oil for compression ignition engines does not deteriorate during storage as rapidly as gasoline, but the storage life is still relatively short. It can be stored in an above-ground vented tank for approximately one year and in an underground vented tank for about three years (41). The longer storage life in underground tanks is due to the lower temperature expected. If, in addition to being underground, the tank is sealed, the storage life can be extended to approximately four years.

The amount of fuel to be stored will, of course, depend upon the size of the engine and the specific fuel consumption. The specific fuel consumption will vary with the type and size of engine, with the smaller engines, in general, showing a higher specific fuel consumption than the larger engines. Air-cooled diesel engines in the size range of 20 hp or less can be expected to show a specific fuel consumption of approximately 0.5 up to about 0.65 pounds per horsepower hr, the fuel consumption increasing as the power rating decreases. Water-cooled, naturally aspirated, engines can be expected to show a fuel consumption of about 0.75 lb hp/hr for the smaller sizes, ranging down to about 0.5 for an engine of approximately 100 hp and somewhat less than this, perhaps about 0.45, for engines of 200 hp or greater. Water-cooled, turbocharged, 4 cycle engines can be expected to show a relatively constant specifi fuel consumption regardless of the power rating. A typical value would be approximately 0.45 lb per hp-hr (41).

SPARK IGNITION ENGINES: The automobile engine, which is relatively familiar to most people, is the most common example of the spark ignition engine. Although most such engines operate on gasoline they are also available for operation on natural gas or liquefied petroleum gas. For auxiliary power generation an industrial type engine which is more conservatively designed, would be preferable to an automotive engine. Spark ignition engines are available in many different forms; there are water-cooled and air-cooled, two and four cycle, naturally aspirated, supercharged or turbocharged. Two cycle

spark ignition engines are generally limited to the smaller sizes, about 10 hp or less, because of their short service life, somewhat lower efficiency, and poor speed regulation. The short service life and lower efficiency may not be too important for the short term application in a shelter, and, therefore, a two cycle engine may be suitable in the small sizes, principally because of its somewhat lower first cost. Supercharged and turbocharged spark ignition engines are not commonly used for industrial service, because of the high temperature problems. There are, however, a few engines of this type, using LP gas, available in the larger sizes.

Industrial gasoline engines in sizes up to about 500 hp are available and are designed to operate at speeds from about 1200 to 3600 rpm. Air-cooled, four cycle engines are available up to about 70 hp and water-cooled, four cycle engines are available from about 3 hp to about 500 hp, using gasoline as fuel. Engines using LP gas as the fuel are basically gasoline engines which have been modified and consequently are available in approximately the same sizes. In addition there are available two cycle and four cycle water-cooled, supercharged engines in the size range from about 225 hp up to about 500 hp.

Spark ignition engines are generally smaller and lighter than compression ignition engines of the same power output, and operate at somewhat higher speeds. Engine-generator sets using spark ignition engines are readily available in sizes from 1 kw and up. A 1 kilowatt set can be purchased for as little as one hundred dollars but this would be a unit for intermittent duty only. For continuous service it would be necessary to pay approximately two hundred dollars for a 1 kilowatt unit. As is the case with the diesel engines, the cost per kilowatt will decrease for the larger sizes, dropping to about one hundred dollars per kilowatt for a 5 kilowatt engine-generator set.

Spark ignition engines show approximately the same sensitivity as compression ignition engines to variations in intake pressure and temperature and exhaust back pressure. When using stored gasoline as the fuel the engine is subject to malfunction of the carburetor due to the gums and residue formed by deterioration of the fuel. The ignition system is also subject to malfunction due to corrosion or moisture which could form

during the storage. Thus the standby maintenance procedures become more important in the case of the spark ignition engine.

From the standpoint of safety, a gasoline fuel unit leaves something to be desired. Gasoline is highly volatile and forms a vapor which is heavier than air. A leak in the fuel system could release the vapors into the shelter where they could form an explosive mixture which could easily be ignited. The exhaust gases from a gasoline engine have a high carbon monoxide content which would be a potential hazard to the health of the occupants if the exhaust is not adequately vented to the outside.

An engine using LP gas as the fuel would be even more dangerous from the standpoint of the volatility of the fuel since the principal constituent of a liquefied petroleum engine fuel is propane, which vaporizes at approximately -40°F at atmospheric pressure. The vapors are heavier than air and will collect in low spots in the terrain. This fact has caused some doubts concerning the suitability of LP gas fuels for an underground shelter.

The specific fuel consumption of spark ignition engines will be somewhat higher than for compression ignition engines. For gasoline, air-cooled engines the fuel consumption can be expected to be from about 0.7 to 0.8 lb per hp-hr. A water-cooled engine of comparable size will probably show a fuel consumption somewhat higher than this for power ratings of about 50 hp or less, decreasing to approximately 0.65 for engines of 200 hp or over. LP gas engines will show a somewhat more favorable fuel rate for power ratings of 50 hp or greater, with a rate of about 0.5 lb per hp-hr being an average value (41).

The storage characteristics of gasoline are the poorest of any of the fuels while, on the other hand, LP gas has probably the best storage characteristics. Gasoline, as purchased from a service station, is normally not stored more than 6 months but may be stored up to one year if loss of some of the more volatile components can be tolerated. This would affect the starting ability but probably would not otherwise affect the usefulness of the fuel. In an underground tank the storage period can be extended to about two years and if the tank is sealed the storage period may be as much as five years.

LP gas is always stored in a sealed tank since it must be under pressure to remain a liquid. The storage life is considered to be at least 10 years and probably longer. Some sources claim that it may be stored indefinitely without deterioration.

Gas Turbines

The theoretical concept of the gas turbine engine is not new, but it has been only in comparatively recent years that technological advances have made it possible to build a practical engine. The chief advantage of the gas turbine is the large power output from a small engine which is basically simple and reliable in its operation. The principal applications have been as large prime movers for power generation and pumping services and for aircraft use. At the present time the automotive gas turbine must be considered as being still in the developmental stage.

There are very few small gas turbines in production at the present time and most of those which are in production are intended for specific military applications. Units as small as 25 hp are listed as available and many units of over 500 hp are actually in service. Since the availability of a unit which would be suitable for shelter application is questionable, it would not be very meaningful to discuss the operation characteristics and economic factors in any detail. Because of the limited production it is very probable that the cost of gas turbine units would not be competitive with other types of engines. Also it might be pointed out that the combustion air requirements for a gas turbine would be from 5 to 8 times as much as for reciprocating engines. This would require large intake air and exhaust ducts which could create serious problems in maintaining the shielding integrity of the shelter.

In summary it can be said that the compression ignition engines would be superior from the standpoint of dependability, operating costs, and safety and that the fuel would have better storage characteristics than gasoline. The spark ignition engines would be superior from the standpoint of availability and low first cost and that LP gas would have the best storage characteristics of any of the fuels. Since LP gas engines are modified gasoline engines, their first cost would be essentially the same as the cost of the equivalent

gasoline engine, plus the cost of the modification which would probably be between 25 and 50 dollars. The gasoline engine would have one additional advantage in that it is the most common type of engine and is most familiar to the average person. In case of operating difficulties it would be more likely that the occupants of the shelter would include one or more persons who would be capable of performing the necessary repair work. Gasoline is also the most readily available fuel and could be obtained from autos or service stations near the shelter if necessary. LP gas engines are probably the least familiar of any of the engines and it would be very unlikely to find a person in the shelter who was familiar with their operation and capable of doing any necessary repair work. Although the basic engine is the same as the gasoline engine, the carburetion system for an LP gas engine is significantly different and would be very unfamiliar to a person who had not had experience with this type of engine.

Heat Released by Internal Combustion Engines

The total heat input to an engine can be determined from the specific fuel consumption and the heating value of the fuel. The product of these two factors will give the heat rate in Btu/hp-hr. The heat rate multiplied by the power output will give the total heat input to the engine in Btuh.

Only a portion of the heat input will be converted into power, the exact amount depending on the thermal efficiency of the engine. The thermal efficiency can be as low as 20 percent, or even less, for a two stroke, air-cooled gasoline engine or as high as 35 percent for a four stroke, water-cooled, turbocharged diesel. Typical values for a four stroke, water-cooled, gasoline engine would be about 25 percent and about 30 percent for a naturally aspirated diesel engine.

The heat which is not converted into power must be removed from the engine. Part of it will leave in the exhaust, part will be removed by the cooling system, and part will be radiated to the surroundings. The exact proportion of heat removed by each method will depend on the type of engine. Table 7.4 taken from Reference 41, shows typical heat balance and heat rejection rates for various prime movers. The data are representative only and there may be wide variations in engines of the same type. Also the heat balance will vary with the load on the engine.

TABLE 7.4

TYPICAL HEAT BALANCES, HEAT REJECTION RATES, AND EXHAUST GAS TEMPERATURES

Performance Parameters	Four Cycle Spark Ignition	Two Cycle Diesel	Four Cycle Diesel TC (a)	Four Cycle Diesel NA (b)
Fuel Energy Converted to Power, %	26	30	35	31
Fuel Energy Rejected to Coolant, %	30	21	22	26
Fuel Energy Rejected in Exhaust, %	32	37	29	30
Fuel Energy Rejected as Radiation, %	12	12	14	13
Coolant Heat Loss Btu/hp-hr	2,900	1,800	1,600	2,100
Exhaust Heat Loss Btu hp-hr	3,100	3,100	2,100	2,500
Exhaust Gas Temp., °F	1,200	600	800	900
Radiation Heat Loss, Btu/hp-hr	1,160*	1,030*	1,020*	1,050*

(a) Turbocharged (b) Naturally Aspirated

* Values added by the author.

For an air-cooled engine all of the heat not converted into power or rejected in the exhaust must be removed by the cooling air. In a liquid-cooled engine part of this heat is rejected to the jacket coolant and must then be disposed of by some other means. Methods by which this may be accomplished include:

1. Engine Mounted radiator
2. Remote radiator
3. Direct make-up
4. Heat exchanger

An engine mounted radiator system would require cooling air and would, therefore, necessitate about the same total quantity of ventilating air for the power system enclosure as would an air-cooled engine. The system requires no supply of water beyond that required for the initial filling except for possible small amounts of make-up water. Of course one of the non-aqueous coolants could be used instead of water. This might have some advantages for inhibiting rust during the storage period.

In order to reduce the quantity of ventilation air required a remote radiator can be used. The radiator can then be located outside of the shelter enclosure where a free circulation of air can be assured. This would require additional piping and, probably, a circulating pump. However this might well be less costly than providing additional ventilating capacity for the power system enclosure. Obviously if the shelter is to provide blast protection, the remote radiator would also require protection against blast and shock.

The requirement for ventilation air also can be reduced by using a direct make-up cooling system. Here the radiator is replaced by a standpipe and a temperature-controlled valve with appropriate water connections to the engine and water supply. The water is circulated through the engine by an engine-driven pump and the temperature sensing element in the hot water discharge line from the engine controls the flow of make-up water. Hot water overflows from the standpipe at the same rate as the cold make-up water is supplied. This system would probably provide the best cooling characteristics of any of the systems but it requires very large quantities of water. It could not be used where water supplies are limited. It might well be considered if an adequate water well is incorporated in the shelter

design. For normal installations, the water should be "softened" before entering the engine in order to reduce the rate of deposition of dissolved or suspended solids since these deposits will reduce the effectiveness of the heat transfer surfaces. For shelter use, however, the system could probably function for two weeks without serious loss of cooling capacity. Thus, it should not be necessary to provide the large and costly water treatment equipment.

The heat exchanger system removes the waste heat of the engine by transfer from the coolant circulating water in a heat exchanger. The circulating water then goes to a cooling tower or spray pond where it is cooled by evaporation and air circulation. This system would require less make-up water than the direct make-up, the exact amount depending on the type of cooling tower or pond used. In a blast protected shelter the cooling tower would be very susceptible to blast damage which might make the system unsuitable for use.

The direct make-up system is contained completely within the shelter and is, therefore, not subject to damage from the blast wave, but a blast valve would be required on the water discharge and supply lines. In any type of system the equipment must be mounted to protect against ground shock if the shelter is to include blast protection.

In any of the systems, waste heat may be recovered from the exhaust gas or the engine coolant, by means of suitable heat exchangers, for use in tempering the shelter ventilation air during cold weather. In many installations this may be the only source of heat for this purpose and in the colder sections of the country could be an important consideration in the design.

The heat which must be removed from the engine room includes the heat produced by the generator. This will, of course, depend on the efficiency of the generator, which may vary from about 65 to 80 percent. If more specific information is not available, an efficiency of 70 percent may be used for estimation purposes. Thus, the output of the generator will be only 70 percent of the shaft power of the engine and 30 percent of the shaft horsepower will be dissipated

as heat to the surroundings. This amounts to about 764 Btu per hp-hr. Since the capacity of the engine-generator set is normally expressed in terms of the generator output, it may be more convenient to compute the heat loss from the output. This can be obtained from:

$$Q = 3413\,(100 - e)/e \quad \text{Btu/kw-hr} \qquad \text{(Eq. 7.2)}$$

Where 3413 is the Btu equivalent of a kilowatt-hour and e is the generator efficiency in percent. For an efficiency of 70 percent, Q would be about 1463 Btu/kw-hr of generator output.

CHAPTER VIII

AIR FILTRATION REQUIREMENTS

In any discussion of ventilation systems for fallout shelters a frequently occurring question is one concerning the need for filters to exclude fallout particles from the ventilation air. Consequently it is worthwhile to discuss the possibilities of entrainment of radioactive particles in the air stream and the possible effects on the occupants of the shelter.

The nature and characteristics of fallout are covered in detail in Reference 3 but can be briefly summarized here. It consists of particles which range in size from a fine dust to several hundred microns in mean diameter. A micron is 0.001 mm or about 0.0004 inches. The fallout material is radioactive because of the radioactive fission products which adhere to the particles of earth, or other materials, which have been pulverized or vaporized by the detonation. The greatest amount of fallout would result from surface or shallow subsurface bursts. These particles are carried upward by the rising column of hot gases and fall back to earth over a period of time following the explosion.

During the time the particles are falling they are carried by the winds to distances which increase with the time required for them to fall back to earth. The rate at which a particle falls depends on size, shape, weight and the characteristics of the air, but, generally speaking, the larger particles fall faster and are less affected by the winds. The smaller particles fall more slowly and are carried to greater distances from the point of origin before reaching the earth. Consequently the particles which settle to the ground at any given distance from ground zero will vary over a rather narrow range of sizes with the average particle size decreasing as the distance increases.

The time of arrival of the various sized particles will depend on the height of the clouds from which they fall and the size of the particle. For example, a particle with an effective diameter of 100 microns would require about 10 hours to fall from a height of 80,000 feet and

reach the ground with a terminal velocity of about 120 feet per minute. If the effective wind speed were 15 miles per hour it would be deposited 150 miles from the point of origin. At this location particles larger than 100 microns would not be deposited since they would have fallen to the earth before reaching there and smaller particles would remain aloft, to be deposited farther downwind.

This simplified analysis does not take into account the possible effects of rain or snow which would tend to "wash" particles out of the air and cause them to be deposited sooner than otherwise would occur nor does it consider the effects of downdrafts or updrafts in the atmosphere. In addition it does not consider the effects of possible multiple bursts of various types, sizes, altitudes and locations which can produce fallout patterns which overlap and reinforce each other.

The radioactive components in fallout from land surface bursts are associated with the particles in such a way that the activity increases approximately as the square of the particle diameter. Thus the highest levels of radioactivity would be associated with the largest particles which would fall close to ground zero and would diminish progressively with smaller and smaller particles reaching the ground at greater and greater distances from the point of origin. The smaller particles, remaining aloft longer, would also undergo considerable radioactive decay before reaching the ground.

Mathematical models used to compute fallout distribution and radiation levels generally do not consider particles less than about 40 microns in diameter since particles smaller than this do not contribute significantly to a standard radiation level greater than 1 roentgen per hour. (The standard radiation density is defined as the observed radiac dose rate 3 feet above a uniformly contaminated open area produced by the total deposited fallout corrected for decay to 1 hour after detonation). When it is considered that particles this size may take 15 hours or longer to fall and, in that time, will have decayed by a factor of 25 or more, it can be seen that they do not constitute a serious threat. Thus the danger of exposure to gamma radiation is associated with particles greater than about 40 microns in diameter.

There are, however, other potential hazards from radioactive fallout which must be considered: (1) inhalation of particulate matter with resulting radiation exposure to internal organs and (2) contact of contaminated matter ith the skin and its resulting radiation exposure.

Inhalation of particulate matter would result in its being deposited in the lower respiratory tract from where soluble material is taken up by the blood. Authorities substantially agree that the hazard is limited to particles less than about 5 microns in diameter since the nasal passages act as an effective filter for larger particles. Particles larger than 30 microns seldom enter the respiratory tract and 10 microns is considered the largest size of any real importance in normal inhalation exposure. From the preceding discussion it is apparent that there is little need for concern about particles this small and there is no need for filtering ventilation air to protect against the possible inhalation hazard.

The contact hazard is concerned almost completely with beta radiation from fallout material deposited on the skin. Exposures of 500 to 1000 rads are required to cause redness and inflammation of the skin and several times hat for more serious burns. Exposures of this magnitude would be expected only from handling concentrated sources of radiation or being exposed directly during the time fallout was being deposited in areas where a disabling dose of gamma radiation would also be expected. Without the gamma exposure the beta burns would be painful but probably not incapacitating. The most important factor here is the gamma radiation since the beta hazard would be minor except in the presence of the more serious gamma radiation hazard. In a shelter, fallout particles entering with the ventilation air might constitute a gamma radiation hazard but, if this were controlled, the beta hazard would be of no serious concern. Consequently there is no need to filter the ventilation air to protect against the contact hazard.

There remains to be considered the hazard from gamma radiation associated with particles greater than about 40 microns. This could be of concern if sufficient material entered the shelter so as to cause a significant reduction in the protection offered by the shelter

against gamma radiation. It is necessary, therefore, to estimate the effect of fallout particles entrained in the ventilation air on the protection factor of the shelter.

There are two main methods by which fallout particles might enter the shelter. The first is through windows which have been opened to permit ventilation or which have been broken by blast effects. The second is through the operation of powered ventilation systems, either those normally encountered in building construction or those provided in a single-purpose shelter.

The first method is of concern principally in the utilization of above-ground areas of existing buildings as fallout shelters. It has already been stated that, in most cases, these areas will depend on natural ventilation and, therefore, it is to be expected that windows will be open. Such facilities are also the most vulnerable to glass breakage due to blast effects.

The velocity of air entering through windows on the windward side of the building will be less than the incident wind speed because of the orifice effect of the windows. The effect varies according to the fraction of the wall occupied by windows and the angle at which the winds strike the wall and for most buildings would be quite large. Reference 27 gives an effectiveness factor of 0.2 to 0.25 and Reference 55 gives an experimental coefficient of 0.2, although there was considerable variation around this value. Air velocities through the windows varied from about 180 fpm to about 230 fpm when the wind velocity was from 6 to 10 mph (528 to 880 fpm).

When these flow rates are compared with average terminal velocities of particles falling in heavy fallout areas (120 to 600 fpm, according to Reference 54) it can be seen that those particles which enter at the windows may be expected to be deposited in the immediate vicinity of the openings.

This conclusion was verified by experiments performed by the U. S. Naval Radiological Defense Laboratory using the natural fallout from the volcano, Mt. Irazu, in Costa Rica. The particle sizes were in the smaller size ranges, with nearly all of them having a diameter

less than 150 microns. About one-third of the deposited mass was in particle sizes less than 40 microns. It would, therefore, have been expected that infiltration of particles should have been at a maximum. Air was drawn in through an open window of an otherwise sealed test house at a constant average face velocity of 425 fpm by means of an exhaust fan.

It was found that most of the fallout drawn in was confined in an area of about 200 square feet with the bulk of the material in the immediate vicinity of the window. The average density of the fallout over the 200 square feet was about 2% of the deposit in the open. If the volcanic fallout had been radioactive it was calculated that the exposure in the center of the deposit in the house would have been about 1/250 of the exposure that would have existed in the open (46).

These data have been applied in the analysis of the possible effect of fallout ingress on the protection factor afforded by large buildings. Calculations were performed for two sizes of buildings, 2000 sq. ft. and 10,000 sq. ft., with and without interior partitions, with various sized window openings and with fallout ingress densities of 2% and 20% of outside level. Of the various variations studied it was found in about three-quarters of the cases that the protection factor was reduced by less than 10%. This is much less than the possible error involved in the calculation of the protection factor by the engineering method. However, in two cases the reduction in protection factor was found to be about 55%. This occurred under the assumption of 20% fallout density spread over the entire floor of small buildings without interior partitions. In these same buildings, assuming 2% fallout ingress, the reduction in protection factor was only 10%.

These analyses indicate that the effect of fallout ingress through open or broken windows is not serious, particularly if shelter areas are located in the inner parts of large buildings having interior partitions. They also show that natural or improvised ventilation is unlikely to draw significant amounts of fallout into shelters provided the shelter areas are not immediately adjacent to open windows. It is on this basis that the development of packaged ventilation

kits for use in group shelters in the United States does not include a requirement for air filters.

The entrainment of particulate matter in the air stream of a powered ventilation system has also been studied. In 1957 the U. S. Naval Civil Engineering Laboratory (USNCEL) made tests on a conventional ventilation system using an aerosol with particle sizes mainly smaller than 10 microns. It was found that the system had little or no effect on particles smaller than about 3 microns but larger particles were trapped or impacted fairly effectively by the system components such as blowers or cooling coils. Essentially no particles larger than about 7 microns passed through the system. Commercial filters of the type normally used in ventilating systems were effective in removing particles larger than about 10 microns.

In 1964 experiments were performed by USNCEL in which particulates in the size range appropriate to fallout were dropped past an inlet fixture fitted with a normal type of conical cap. The volume of flow through the fixture was 600 cfm with an inlet velocity of about 200 fpm. It was found that no particles larger than 60 microns were taken into the fixture. In the size range of 30 to 60 microns about 40% of the particles were taken in and almost all of the particles smaller than 30 microns were captured. The capture area for this particular experiment was about 5 sq. ft. surrounding the inlet fixture (48). Calculations were also made of the radioactivity level which would result from the captured particles if collected on a filter or passed into the shelter. In all cases the levels were much less than the amount reaching the occupants through the walls of the shelter even assuming outside levels of 10,000 roentgens per hour.

These and other studies suggest that filtration for fallout particles is generally unnecessary unless the intake velocity is quite high and the intake is unprotected by a hood. The intake should be protected to prevent downward or sideward entry of the air. In other words, the air should enter the intake in a vertically upward direction.

For shelter areas in buildings with an existing ventilation system, even with unprotected intakes, the blowers, coils, and standard commercial filters will

be adequate to eliminate all but an insignificant portion of the fallout particles.

These considerations have led to the statement in Office of Civil Defense Technical Memorandum, Technical Requirements for Fallout Shelters; "No filters are required on mechanical ventilation systems other than those necessary for the normal daily use of the space."

The discussion above has been concerned with the possibility of infiltration or entrainment of fallout particles during the time the radioactive particles are actually falling. Once the fallout has ended and the particles have been deposited on the ground and other surfaces there is little likelihood that they will be picked up by the ventilation. Particles deposited on a window sill could be blown in through the open window but this would be a very insignificant amount in most cases.

Protected ventilation intakes should be located with at least 24 inches between the horizontal surface beneath them and the bottom of the protective cap. Under these conditions no particles of any significance will be picked up.

Thus the period during which there would be any possible hazard is only during the time the fallout is being deposited, a matter of only a few hours in most cases. If necessary the windows could be closed (if they were not broken) or the ventilation rate reduced during this comparatively brief period in order to minimize the hazard. The occupants could probably tolerate the resulting increase in effective temperature for the short time involved.

CHAPTER IX

WATER AND SANITATION REQUIREMENTS

Water is essential to human life. It is an established fact that human beings can survive much longer without food if they have sufficient water than they can without water. It is, therefore, necessary that some consideration be given to water requirements and sources of water for survival shelters.

The availability of water and recovery of water supply systems is a major concern in the civil defense structure in the post-attack period. However, this discussion is concerned only with in-shelter aspects of the problem and does not attempt to cover the many important problems which must be solved in the post-shelter period.

In considering water requirements, as well as other criteria, it is probable that a distinction should be made between shelters licensed, marked and stocked under the National Fallout Shelter Survey and facilities which have been designed to serve as shelters. In most cases shelters identified in existing buildings by the Shelter Survey were not intentionally designed into the structure. They exist more or less by happenstance. It is unreasonable, therefore, to expect such facilities to meet shelter criteria which were established long after construction was completed. However, as long as a shelter deficit exists, such facilities are required to offer the population at least a minimum chance for survival. The criteria for such shelters are, therefore, the minimum which is consistent with survival.

Over a period of time, the shelter development program is expected to create more and better shelters to replace existing minimal facilities in the shelter inventory. The design objectives of such new shelter may be considerably different from the bare survival criteria applied to existing spaces. The new facilities should be designed on the basis of the best and latest information available. As research develops more reliable information and better design techniques, the design objectives for new facilities may change. This would not necessarily result in a change in the minimum criteria applied to existing shelter spaces although it is possible that new information may reveal that

these minimum criteria are not compatible with survival. In this case, consideration would have to be given to changing the criteria.

Under the NFSS program, shelters which meet the minimum criteria are stocked with food, water, sanitation kits, radiological monitoring instruments, medical supplies, and in some cases, ventilation kits. In reference to water supply, the Federal Civil Defense Guide states:

> "The requirement for a supply of potable water necessary for survival constitutes one of the fundamental problems in achieving shelter habitability. A minimum of 3½ gallons for each shelter space stocked should be available. This amount must be furnished either from sources available to the shelter or from water storage containers."

Sources available to the shelter might include wells, tanks, gravity-flow community systems, entrapped water in building systems, or a combination of these sources. Water storage containers often would be furnished as part of the shelter stock but, of course, other types of suitable containers could be used.

Building systems which might contain either potable or nonpotable trapped water could include:

Fire control tanks
Sprinkler systems
Hot water heaters
Supply pipes
Holding or gravity tanks
Water closet flush tanks
Air conditioning or chilled water systems
Heating tanks and systems
Indoor swimming pools
Hydraulic elevators using water
Reflector pools within building

Before trapped water can be included in the shelter plan certain basic conditions must be met:

1. The potability of the water is established initially by a determination that the water is part of the supply normally furnished from an approved source, or that tests have been conducted to assure a safe level of bacteria and chemical content.

2. A cutoff valve is installed (if not already in place) to avoid admittance of water which might be impure into the system. When turned off, this valve will also prevent syphoning of water in the system back into the main under conditions where the pressure in the main is greatly reduced.

3. The water is not contaminated by chemicals added for inhibiting corrosion or lowering the freezing point.

4. Suitable devices and services for dispensing water within the shelter are available including a valve or faucet which may be opened at the top of the system to permit drainage below.

5. Water is available without dependence upon electric powered pumps, unless emergency power is available to drive such pumps.

6. Water is available throughout the year under extreme weather conditions, considering also the possibility of freezing due to heating system failure caused by power loss or other failure.

In some buildings the water supply is from separate wells rather than from a municipal system. In this case a determination should be made that the required quantity of water will be available to the shelter under conditions of electric power failure and during all seasons of the year. It is assumed that, if this is the normal water supply, the water is of potable quality. If, however, potability depends upon treatment of the water, a determination must be made that the treatment facilities will remain in operation.

In communities which have a central distribution system of the gravity-flow type, this source of water may be available for shelter use. A determination should be made that continued operation and protection against bacteriological contamination is assured before including water from this source in the shelter plan.

Water containers furnished for use in fallout shelters are filled at the shelter site. Filling instructions require:

1. Water used be from a source approved by State and local health departments;

2. The greatest care be exercised during the filling operation to assure sanitary conditions;

3. The filling operation be under the care of a State or local health department sanitarian;

4. As an added precaution, one to two tablespoonfuls of household liquid bleach (active ingredient 5.25% sodium hypochlorite; 94.75% inert ingredients) should be added to each drum.

It is provided that the equivalent to the liquid bleach in solid form may be used where approved by local health authorities. Chlorine tablets are readily available and may be preferable to the liquid bleach due to ease of handling and better consistency in measuring the amount of disinfectant added. The number of tablets to be used should, of course, be determined by the health authorities.

The steel drums which have been used to stock many existing shelters hold 17½ gallons of water and vary somewhat in size from a minimum of 15¼" to a maximum of 16 1/8" inside diameter and a minimum of 21 5/8" to a maximum of 23 3/8" inside height. They weigh 10 lbs. empty and 156 lbs. when filled with 17½ gallons of water. The number of drums to be stocked

for water storage is determined from the following formula:

$$\frac{(3.5 \times A) - B}{17.5} = C$$

Where:

A = Number of spaces stocked

B = Quantity of potable water estimated to be available from existing facilities, gallons

C = Number of drums required for potable water

The water drums cause some problems in provisioning shelters. They average about 3.8 cu. ft. each and provide water for five persons. This is 0.76 cu. ft. per person. When it is considered that storage space is determined on the basis of 1.5 cu. ft. per shelter space, it can be seen that about half of the storage space is taken up by the water drums. In fact, if the water drums are not required, the storage space is determined at 0.6 cu. ft. per person.

In addition to the space problem, the water drums can create a problem of floor loading. Each drum when filled has a dead load of about 112 lb. per sq. ft. It is sometimes necessary to stack the drums two or three tiers high in order to attain maximum utilization of storage areas. Thus, floor loads, thus created, could well exceed the maximum safe load for the structure.

In considering the design objectives for a new structure, which will incorporate a fallout shelter, or for a facility specifically designed as a shelter, a different

approach to the problem of water requirements and supply can be justified. A logical starting point is to consider the moisture evaporated from the body by perspiration. Table 3.6 gives the moisture evaporated by sedentary adults for various dry bulb temperatures. This data is extracted from Table 3.6 and repeated in Table 9.1 with the figures converted to lb/day and qt/day. The conversion from pounds to quarts is based on 8.33 lb/gal for water.

TABLE 9.1

MOISTURE EVAPORATED BY SEDENTARY ADULTS

Dry Bulb Temp. °F	Moisture Evaporated		
	lb/hr	lb/day	qt/day
50	0.062	1.488	0.714
60	0.067	1.608	0.772
70	0.096	2.304	1.106
80	0.173	4.152	1.993
90	0.274	6.576	3.156
100	0.384	9.216	4.424
110	0.499	11.976	5.748

The moisture evaporated by the body, and the requirement for water intake to replace this loss seems to be more a function of the dry bulb temperature than of the effective temperature. The environmental criteria is 90% reliability of maintaining a 24-hour average of 82°F effective temperature. From the standpoint of minimum dry bulb temperature the best condition to meet this criteria would be a 24-hour average of 82°F dry bulb and 82°F wet bulb (100% relative humidity). Any other combination of wet bulb and dry bulb temperatures to yield 82° FET would result in a dry bulb greater than 82°F.

Using a straight line interpolation of the data of Table 9.1 gives a moisture loss of 2.226 qt/day at 82°F dry bulb.

The data in Table 9.1 give the evaporative heat loss only. This would include insensible perspiration and

sweating. Not included is moisture loss in the urine and feces or for any other reason. When these losses are included the total moisture loss is much greater than indicated in the table. Reference 20 gives a chart showing the daily water requirements to avoid dehydration in man at rest. This curve is redrawn in Figure 9.1 with the data from Table 9.1 plotted as a dotted line for comparison. At 82°F dry bulb the water requirement is indicated at about 3½ qt/day.

The available data on water consumption during shelter occupancy tests appears to indicate that the actual water consumption will tend to follow the evaporative heat loss curve. In these tests the occupants were allowed all the water they wanted but a certain amount of control was exercised by the manner in which water was dispensed. In fact, in those tests where controls were not used the water usage was significantly higher and the amount of waste water was also much higher. This would tend to indicate that occupants will waste water when no controls are exercised but will consume about the amount required to replace the evaporative heat loss when allowed all the water they want under reasonable control. On this basis, Figure 9.1 would suggest that there might be some dehydration since the water consumption is less than the total moisture loss. A very limited amount of evidence from the occupancy tests seems to confirm that this is the case. The evidence is, however, far from conclusive. It is probable that this dehydration weight loss would not be great enough to be of serious physiological significance.

Dehydration of the body tissues can be a serious problem if it is prolonged. The operational effectiveness of the body is impaired if the loss of body water exceeds 5 percent of body weight and survival is unlikely if the loss exceeds 20 percent of body weight. While it is not unusual for an athlete to lose 10 pounds or more due to sweating during a game, this loss does impair his efficiency and the water is, of course, replaced very soon after the game is over.

Under shelter conditions the dehydration would progress from day to day if a serious water deficit exists and there would be no way of replacing this moisture in the body. Under these conditions over a period of ten days to two weeks it is possible that the loss of body fluids could prove fatal to some occupants of the shelter and that most occupants would suffer impairment of their physical efficiency.

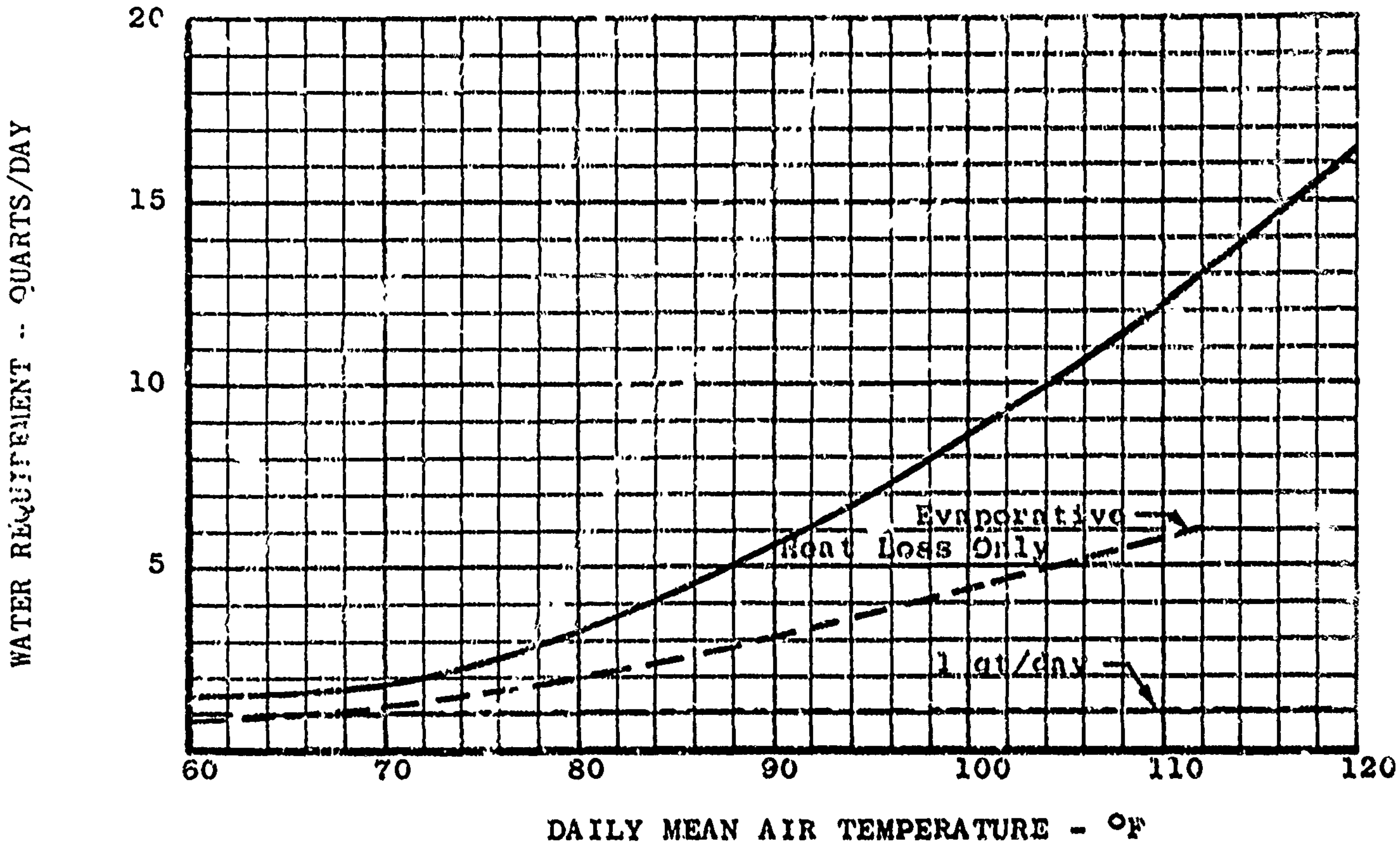


FIGURE 9.1 - DAILY WATER REQUIREMENTS TO AVOID DEHYDRATION IN MAN AT REST

For these reasons, it is imperative that shelter occupants be given water to drink whenever they ask for it, regardless of the water supply available in the shelter. It would be necessary, of course, to control the dispensing of water to prevent waste when supplies are limited but this control must not be extended to the point of limiting the water intake of the occupants. Even if the rate of consumption should indicate that available water supplies would be exhausted before the end of the anticipated occupancy period, the water should not be rationed below that required to maintain the body moisture content. It is quite possible that the reduction in radiation levels due to decay would allow persons to leave the shelter for short periods to obtain more water. It would even be permissible to drink water which is contaminated with radioactive fallout since the ingestion of some fallout would not necessarily be fatal.

On the basis of this discussion, it is suggested that a design objective would be to provide as much potable water as possible within the limits of available budget, space and other design criteria.

The requirement for potable water other than for drinking and food preparation cannot be determined with any precision since it will vary with the circumstances and the type of shelter facility.

It would be highly desirable to have water available for washing hands after using the toilet facilities in order to prevent the possible contamination of the stored water supply. This need might be met by use of a waterless hand cleaner followed by immersion in a disinfecting solution and thus eliminate the need for water.

Some water of potable quality should be available for medical purposes. Although medical care in the shelter will normally be limited to first aid treatment, it is still necessary to have water available for the first aid attendant to wash his hands and to cleanse body areas before treatment.

Shelter areas in hospitals or other facilities where professional medical care would be available would have a greater requirement for water. Office of Civil

Defense Technical Memorandum 65-1, "Technical Requirements for Fallout Shelters in Hospitals," gives a minimum of 5 gallons of water for each patient and one-half gallon per person for patient care staff for daily consumption. This is intended to provide water for all purposes, including drinking, cooking and sanitary purposes.

The water requirement for medical purposes and for personal hygiene may thus vary from one-half gallon per person per day to as much as five gallons per person per day depending on the facilities available in the shelter. A suggested minimum criterion for potable water might be one gallon per person per day for drinking, food preparation, personal hygiene and medical requirements. This would be increased when an evaluation of the shelter facilities indicates a need for a greater supply of water.

NON-POTABLE WATER REQUIREMENTS

It is not possible to establish criteria for a supply of non-potable water since this would be completely dependent on the facilities and equipment in the shelter. In many NFSS shelters there would be no requirement for non-potable water since there would be no special facilities included in the shelter. In some specially designed shelters the requirements for non-potable water could be very extensive.

Some of the needs for non-potable water might include the following:

1. Water for bathing or showers. Very few fallout shelters will provide bathing facilities but some more sophisticated installations such as emergency operating centers or military shelters may include decontamination showers.

2. Cooling water for auxiliary power systems. The amount of water required would be determined by the size and type of system installed and the type of cooling system used on the engine.

3. Water for mechanical cooling systems. This would include water for air conditioning condensers, cooling towers, evaporative cooling systems, or well-water cooling systems. The amount of water will depend on the type and size of the installation.

4. **Water for fire fighting.** In most cases it will probably be impractical to depend on water for fire fighting unless an almost unlimited supply is available.

5. **Water for waste disposal.** The amount required will depend on the type of sanitation system used. If the municipal sewer system is functioning and flush toilets are used the water requirement could be 25 gallons per person per day or more. This would probably not be feasible unless the municipal water system were functioning or the shelter facility included a well.

With the large variation in possible requirements for non-potable water it is necessary to evaluate each shelter facility on an individual basis to determine the minimum supply which must be available. This would be impractical for NFSS shelters because of the time and expense involved. For structures where shelter is to be included in the design this evaluation would be a part of the design procedure for the mechanical systems.

Water which is polluted or contaminated can be used for many of these applications, as long as the pollution is not such as to clog piping, valves or other parts of the system. Even in this case the pollutants can often be removed by filtration. Water which is contaminated by radioactive fallout can also be used if precautions are taken to shield the equipment from the occupants of the shelter and the equipment operators. Radioactive contaminated water should not, however, be used in sanitation systems since it would be inside the shelter in close proximity to the occupants.

SOURCES OF WATER

In NFSS shelters it is necessary to provide for the water requirements from sources which already exist or by storage in containers in the shelter. For facilities where shelter is incorporated in the design it is sometimes possible to make provision for a water supply as part of the design.

The most desirable source would be the normal water supply system since this would provide an almost unlimited supply of potable water. If the normal supply is a municipal system it is necessary to make some

evaluation of the probability of the system remaining in operation under fallout conditions. If it is assumed that there is no damage from blast or fire the system should be operable. Whether or not it can remain in operation will depend on whether there is shelter for the operators and whether the plant can be operated from the shelter area. Power will be necessary to operate the pumps, chlorinator and controls so that emergency power equipment would be necessary to assure continued operation.

Many water supply systems already have emergency power installations to keep the system in operation in case of power failure. Some have provided fallout protection for the operating personnel. Shelters served by such systems quite possibly would have water available under fallout conditions. In some localities the water supply system is gravity operated and might well remain in operation even without power to operate the pumps.

In some buildings the normal water supply is from their own wells. In this case, the only requirements to maintain water supply is to have power to operate the pumps and to keep any treatment system in operation. Even if the water is not of potable quality and the treatment system is not operating, it could be possible to purify the water by filtering and boiling or by the use of chemical disinfectants.

Boiling water to purify it would probably not be suitable for use in a shelter because of the large amount of sensible and latent heat which would be released to the shelter atmosphere. It would also require a large supply of fuel.

Chemical disinfectants which could be used would be liquid chlorine laundry bleach, chlorine tablets, tincture of iodine or iodine tablets. Most household laundry bleaches have instructions on the label for the amount to use for water purification. Chlorine or iodine tablets may be purchased at most drug or sporting goods stores with instructions for use. Two percent tincture of iodine is added at the rate of 5 drops per quart of clear water or 10 drops per quart of cloudy water, followed by a 30 minute settling period before the water is safe to drink.

Neither boiling nor chemical disinfectants will remove radioactive contaminants from water. Filtering the

water through a bed of sand or earth will remove most of the suspended particles but will not remove the dissolved radioactive materials. It may be, however, that the dissolved radioactivity would be low enough to permit drinking the water. Removal of any large portion of the dissolved radioactivity would require rather sophisticated ion exchange treatment.

The advantages of having well water available to a shelter have been discussed in previous chapters and need not be repeated here. If the cost of the well and pump installation can be justified it should certainly be included in the shelter design.

If neither the normal water supply or a well can be relied upon to provide the required water for a shelter it will probably be necessary to provide for storage of water in the structure. In the case of a building being slanted to include shelter this might be done by incorporating a storage tank in the water system or deliberately increasing the amount of trapped water in the building.

A water storage tank in the system should be located at the roof level or high point of the system. The main supply would feed into this tank with a check valve in the line to prevent draining the tank in case of loss of pressure in the main. Water would be distributed from the tank to the building by normal piping. In this manner there would be a full tank of fresh water available at all times. The only additional requirements would be appropriate outlets in the shelter area and a valve or vent at the top of the system which could be opened to permit gravity flow from the tank to the shelter areas.

It should not be overlooked that in many buildings there would be a significant amount of liquids stored in the building. This would be in the form of canned or bottled carbonated beverages, fruit juices or other beverages. Canned fruits and vegetables also contain large amounts of liquids as do some other canned foods such as stews. Such foods and beverages might be available in dispensing machines, food service facilities in commercial buildings or in the kitchens in apartment buildings. In addition to supplying vital liquids these would supplement the survival rations in the shelter stocks and provide some variety in the diet. Since it is not possible to predict how much of these foods and beverages might be

available at any given time, they should probably not be depended upon as a primary source of supply.

An indoor swimming pool would provide thousands of gallons of usable water for a shelter without need for any special piping or other equipment. The water could be merely dipped out as needed. Even if the pool area had a very low protection factor, the exposure time required to obtain water would probably be short and the increased radiation dose could be tolerated. An outdoor pool would not offer the same advantages but the water might be used if it could be drained into the shelter area as needed. This would require special piping and valves which would be possible if included in the design of the pool.

Other sources which might be considered as possibilities for a supply of water would be trapped rain water, covered or open reservoirs or natural water such as lakes or rivers. There are problems associated with utilization of these sources which would probably eliminate them from consideration in most cases. The principal problem would be getting the water to the shelter. There is also the question of possible pollution or radioactive contamination. However, under some circumstances, one of these sources might be made available to a shelter.

Another possiblity which might be considered is water from fire mains and hydrants. Of course, sprinkler systems or fire control tanks are an excellent source of trapped water in a building and should be considered in determining the water resources available. In some localities, however, the fire mains are a separate system from the water distribution mains and the possibility exists that water might be available from a fire hydrant, or fire hose in a building, even when the water distributing system is not operating.

SANITATION REQUIREMENTS AND SYSTEMS

In a shelter it will be necessary to have a method for disposing of garbage, trash and human waste. Under fallout conditions there will be no collection of garbage and trash by municipal services. Sewer systems depend on water carriage of waste and power to operate pumps and treatment plant and, therefore, may not be operating.

In NFSS shelters it will be necessary to provide for waste disposal with the facilities which are included in the building or which can be added within the limitations of cost and available space. For facilities where shelter is incorporated in the design it may be possible to make provision for waste disposal under emergency conditions beyond what could be added to an NFSS shelter.

The supplies and equipment furnished in the stocking program for public fallout shelters includes sanitation kits. Two types of kits are furnished: Kit III with supplies for 25 spaces and Kit IV for 50 spaces. The kits are supplied in fiber drums approximately the same size as the steel water drums, one kit of either type per drum. The contents of these kits are shown in Table 9.2.

TABLE 9.2

CONTENTS OF OCD SANITATION KITS

Description	Unit	Quantity Kit III	Quantity Kit IV
Paper, toilet tissue	Rolls	5	10
Seat, commode, plastic	Each	1	1
Opener, can, hand-operated	Each	1	1
Pads, sanitary, heavy	Dozen	1	2
Pads, sanitary, regular	Dozen	2	3
Hand cleaner[1], waterless, pint	Can	1	1
Gloves, polyethylene	Pair	1	1

TABLE 9.2 (Continued)

CONTENTS OF OCD SANITATION KITS

Description	Unit	Quantity Kit III	Kit IV
Spout, dispensing, water	Each	1	1
Tie wires, bag closures	Each	1	1
Cups and lids[2]	Each	35	70
Commode chemical[3], liquid, bottle	Each	1 pint	1 quart
Commode chemical[3], granular, packet	Each	6	12
Bag liners, polyethylene, commode	Each	1	1
Instruction sheet	Each	1	1
Fiberboard boxes	Each	2	2
Fiber drum	Each	1	1

1. This item not included in later procurement

2. Plastic cups in quantities of 40 and 80 were delivered under initial procurement. More durable plastic coated cups were specified later.

3. Only one of these items furnished per kit. Initial procurement provided a liquid commode chemical with iodine base. Later procurement provided a granular quaternary compound in packets of 10 grams each.

The fiber drum in which the sanitation kit is packed is the receptacle for the initial chemical toilet provided in the shelter. The metal water drums are intended for this use after the water is consumed. The number of steel water drums to be requisitioned for sanitary purposes is determined by the following formula:

$$\frac{(2.1 \times A) - D}{15} - F = E$$

Where: A - Number of spaces stocked

D = Quantity of sewage estimated to be removable by means other than drums, gallons

E = Number of steel drums required for sanitary purposes

F = Number of fiber drums furnished (one for each sanitation kit)

2.1 = Minimum number of gallons of capacity required for human waste disposal per shelter space stocked

15 = Number of gallons capacity per drum to sanitary fill line

The number of steel drums to be requisitioned would be the number required for water supply or the number required for sanitary purposes, whichever is greater.

Note that the drums are intended for disposal of human waste only and that they hold 15 gallons as sanitary containers rather than 17½ gallons. When used for sanitary purposes the polyethylene liner is to be closed with plastic wire ties when full. The drum cover is replaced and the drum is stored for disposal after the shelter occupancy period is ended. Food scraps, empty cans, waste paper and other trash are placed in plastic bags, closed with wire ties and stored for later disposal.

Conditions which may permit the removal of waste by means other than the use of drums might include:

1. A sewage system of the gravity type which is likely to remain operative even under conditions of greatly reduced flushing water.

2. Manholes may be available in a protected location in or near the shelter for direct deposit of human waste, either packaged or

from an improvised commode. Both sanitary and storm sewers may be considered under emergency conditions.

3. Existing toilets may be used to dispose of semi-liquid waste. This may be done by forcing the waste with a small amount of flushing water through the traps, using a plunger or other device, or by using non-potable water diverted from other building systems or poured from a container for flushing purposes. Removal of fixtures for deposit of the waste into the sewer pipe may also be considered as an emergency measure.

The 2.1 gallons per person of human waste used to determine the required number of steel drums does not refer to any specified length of shelter occupancy. This is also true for the 3½ gallons per person of potable water used for NFSS shelter stocking criteria. If both are related to the same period of time, a ratio of 0.6 gallons of waste per gallon of water intake is obtained. This conforms very closely to the accepted average values for a water balance of the average man. These values anticipate a normal diet whereas under shelter conditions there will probably be a lower than normal intake of food and water as well as a lower metabolic rate.

The literature reveals rather considerable variation in the data on waste production in a shelter ranging from 0.12 gallons per person per day to as high as 0.45 gallons per person per day. These variations are probably due to different methods of measuring the amount of waste, whether or not the waste includes garbage and/or trash as well as human waste, whether wasted water is included, variations in diet and water intake and different levels of effective temperature. As a consequence it is difficult to determine a reasonable basis for planning the required capacity of a sanitation system for shelter use.

One fact is apparent from these studies. That is that the ratio of waste production to water intake is greater under winter conditions of low effective temperature than it is at high effective temperature. Under conditions of high effective temperature, a greater portion of the water intake is rejected as

perspiration. At low effective temperatures, thermal balance of the body is achieved without activating the sweating mechanism and water balance is maintained by rejecting the water as urine. Thus the winter waste production/water intake ratio may be in the range of 0.7-0.75 rather than 0.6. It would, therefore, be reasonable to assume that winter waste production ratio, say 0.7, combined with a summer liquid consumption rate would give a reasonable basis for design.

If a summer water intake of two quarts per person per day is assumed, the liquid waste production would be 1.4 quarts or 0.35 gallons per person per day. To this should be added some allowance for solid matter in the waste. A suggested criterion would be a total of 0.5 gallon per person per day for human waste.

If the 0.5 gallon per person per day criterion is used to determine the number of steel drums required, the basis for requisitioning would have to be re-evaluated. If the shelter stay time is assumed to be 14 days, for design purposes, the required capacity is 7.0 gallons per person. This is just about one drum for every two shelter spaces since 14 gallons is a reasonable capacity of the drums for sanitation purposes. Due to the greater capacity of the drums as water containers it would require one drum per 2½ spaces if 0.5 gallon per person per day is assumed. Thus more drums would be required for sanitation purposes than for water storage.

If extra drums are required for sanitation purposes it may seem logical to fill them with water so that extra water would be available. Although this would be desirable, it may not be possible or practical. The extra drums could create a problem of storage space and necessitate stacking them several tiers high to take advantage of what space is available. If they are full of water the allowable dead load on the floor could be exceeded. In addition, it might be very difficult to remove the drums from the top tiers for use. Thus it may be necessary to store the drums empty. They could, however, be filled at the time the shelter has to be occupied if time and water availability permit.

Even though there are problems associated with the use of empty water storage containers for sanitation purposes it may well be that minimum requirements for

waste disposal can be met in no other feasible manner. It would, however, be desirable to make some other provision to replace or supplement this method if conditions permit or if it can be incorporated in the design.

The usual methods used for sewage treatment would not be feasible for shelter use because of their cost, complexity, and requirement for large amounts of water. Some of them also require large areas of land for settling basins and aeration. Septic tanks or cess-pools offer some possibilities but both require a water supply to carry the sewage and a drainfield or other method of disposing of the effluent. In the case of a basement shelter, pumping of the sewage would be necessary.

Of the various sanitation systems in normal use, the principle of the pit privy seems most adaptable for use under emergency conditions. There is no need for water or power for operation, there is no complicated mechanism which would require trained operators and it could accept all types of garbage as well as human waste. The only requirements are for effective disinfection and for venting to the outside to remove noxious odors and possibly dangerous gases which would be generated.

Even though the basic principle is adaptable for shelter use, there are not units or systems which have been designed for shelter use. There are portable units which are used on construction sites but these would occupy too much space to be stored in or near a shelter. It might be possible to design simple components which could be stored disassembled and bolted together when needed, but this would have to be done as an individual design since no such units are currently available.

In any shelter where it is necessary to use drums for water storage the most feasible emergency sanitation system seems to be the dual use of the drums as contemplated under the NFSS shelter stocking program. In shelter facilities where water will be available without use of the drums, it will probably be necessary to arrange for emergency use of existing toilet facilities or store extra drums for sanitation purposes.

Under shelter conditions the possible contamination of the shelter water supply and spread of infectious

disease makes strict sanitary practices mandatory. Even with chemical treatment of the waste to retard bacteria growth it should be required that hands be washed after using the sanitary facilities. This would be especially important for those handling food or water in the shelter. This requirement for hand washing could increase the requirement for potable water as previously mentioned.

All water containers in the shelter should be kept tightly closed except when water is being dispensed from them and disinfection of opened water containers should be routine.

The decomposition of waste in a closed drum could cause a pressure build-up sufficient to rupture the polyethylene liner. Such an accident could contaminate food and water supplies as well as expose the occupants to disease bearing organisms. Immersion of the waste in liquid would tend to reduce the generation of gas and control odor production but this would require additional available water in the shelter as well as decrease the waste capacity of the containers. Filled containers should be stored outside the shelter if possible so that contamination from a possible accident could be minimized. This would also conserve space in the shelter.

Mixing food scraps with human waste would tend to increase the production of gases and odors. Therefore, food scraps should be stored in plastic bags and stored for later disposal. Each day's scraps should be placed in a separate container to avoid innoculating the new scraps with bacteria from the older, decomposed scraps. Highly absorbent waste such as diapers and sanitary napkins should be stored separately since they would thus reduce the effectiveness of chemical bacteria and odor control.

Under shelter conditions it would be very difficult to eliminate completely the generation of odors from the sanitary facilities. In order to reduce the possibility of spreading these odors throughout the shelter the sanitary facilities should be located close to the ventilation discharge. In this manner, the odors would be carried out of the shelter by the ventilation air. Air from the waste disposal area should not be recirculated to the shelter unless it has been passed through activated charcoal filters to remove the odors. It would also be desirable to pass it through high efficiency particulate

filters to remove biological organisms. Since filtration systems of this degree of sophistication would seldom be provided in a fallout shelter the best practice would be not to recirculate this air.

CHAPTER X

LIFE SUPPORT SYSTEMS

In Chapter V a method was presented for the solution of the heat transfer from an underground shelter with no ventilation heat loss. This assumed "buttoned-up" operation of the shelter with the ventilation intake and discharge sealed. One possibility which might require operation without ventilation would be the case of an underground shelter with a mass fire at the surface.

For most fallout shelters, especially NFSS shelters, the possibility of operating without ventilation will not occur since it would not be possible to seal the shelter against air exchange with the surroundings. Also they would not be provided with the necessary equipment to permit operation for more than an hour or two without ventilation. Such shelters would probably have to be abandoned if circumstances were such that ambient air could not be used for ventilation. For single purpose, blast-designed shelters or emergency operations facilities, proper selection of the site can virtually eliminate a requirement for buttoned up operations. Even for dual purpose blast shelters, the site location can reduce to a very low level the probability of extended button up time. Thus life support requirements should seldom impose any special conditions on shelter design. If a shelter should be designed for a location where there is a low probability of using ambient air for ventilation the requirements presented in this chapter must be considered.

When complete closure of the ventilation intake is required, the exhaust vent must also be sealed since outside air could enter through it. This would also apply to other openings such as sanitation vents or air intake and exhaust for power systems. Under these conditions several environmental hazards must be eliminated if the occupants are to survive.

1. Oxygen must be supplied to the air to replace that which is used.
2. Carbon dioxide must be removed to prevent concentrations from becoming too high to sustain life.
3. Odorous and toxic substances must be removed from the air.

4. The thermal environment must be controlled to prevent excessive rise in effective temperature.

The limit criteria for concentrations of carbon dioxide and oxygen were discussed in Chapter III, where it was stated that a life support system for one day of closed shelter operation should maintain volumetric concentrations of 1 percent or less for carbon dioxide and 17 to 21 percent for oxygen. The limiting concentration of carbon dioxide will develop before the oxygen is depleted to a corresponding level. The suggested concentrations allow some margin of safety since oxygen concentrations as low as 12 percent and carbon dioxide concentrations of 4 percent can be tolerated, although with considerable discomfort.

The stay time for various concentrations of carbon dioxide and oxygen and the net volume of space per person can be determined from Figure 4.1. Although the length of time during which closure will be required is impossible to predict, a closure time of 24 hours is recommended for design purposes.

Using a CO_2 concentration of 2 percent and referring to Figure 4.1, it is found that the maximum stay time is about 12 hours, even for a unit volume of 500 cubic feet per person. This unit volume is much higher than that allowed in most shelter designs. If a more realistic volume of 75 cubic feet per person is taken, the stay time for a CO_2 concentration of 2 percent is found to be about 2 hours. Increasing the allowable CO_2 to 4 percent would increase this to only four hours.

Under both conditions the oxygen concentrations would be within tolerable limits (about 18 percent and 15.5 percent respectively). If, however, the CO_2 were controlled at the desirable level, the oxygen concentration would determine the stay time. Using 17 percent oxygen and 75 cubic feet per person would give a stay time of somewhat less than 3 hours. If the oxygen is allowed to decrease to 15 percent, the stay time can be increased to about 4.5 hours. It is obvious that, if 24 hour closure capability is to be provided, some means must be available to supply oxygen and to remove carbon dioxide.

METHODS FOR SUPPLYING OXYGEN*

Methods which can be used to supply oxygen include:

1. High pressure cylinders
2. Liquid storage
3. Chlorate candles
4. Potassium superoxide
5. Sodium superoxide
6. Hydrogen peroxide
7. Electrolytic methods
8. Photosynthesis

Of these, the most practical methods for supplying oxygen for a shelter are the use of high pressure cylinders or chlorate candles. The superoxides offer the attractive possibility of absorbing carbon dioxide as well as producing oxygen but they are strong oxidizing agents which react explosively with combustible materials. They also can cause severe burns on contact with the skin, the dust is irritating to the eyes and they are highly toxic if taken internally. Hydrogen peroxide, in the concentrations which would be necessary to produce appreciable amounts of oxygen, is also highly dangerous to handle being subject to spontaneous combustion when in contact with combustible materials. It can be detonated by a slight shock or increase in temperature. The electrolytic methods require complicated equipment and large amounts of power.

Cylinders of oxygen are readily available from industrial supply companies. They are available in various sizes but the most common size holds about 220 cu ft at standard pressure and temperature at a cylinder pressure of about 2000 psi. Table 3.1 indicates an oxygen consumption rate of 0.8 cu ft/hr for a sedentary person and a rate of 1.20 cu ft/hr for persons standing or strolling. Since there would be some activity in the shelter a consumption rate of 1.0 cu ft/hr per person might be used as an average value. On this basis, a standard oxygen cylinder would provide about 220 man-hours of oxygen or enough for about nine persons for 24 hours.

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*The discussion on Life Support Systems in this chapter has been taken from Reference 64, which was, in turn, based on Reference 66.

The cost of the oxygen in the cylinder is quite low, running about three cents per cubic foot. In commercial use a deposit on the cylinder is charged, which is refunded if the cylinder is returned within a specified time, usually 30 days. After this time a demurrage charge is made. For shelter use the cylinders would have to be stored for long periods of time and demurrage charges would become prohibitive. Consequently, the cylinders would have to be purchased. The cost will vary depending on the number purchased. If purchased in large quantities the cost might be about $50 for the cylinder and gas. The cost per man-hour would therefore be about 23 cents.

Oxygen from cylinders should be fed through a standard welding type pressure regulator and a small gas flow meter, probably of the rotometer type. If more than one cylinder is required, they can be manifolded and one pressure regulator and flow meter used. Alternately the regulator and flow meter could be moved from one cylinder to another as needed. The cost for the metering equipment and manifold should be included when determining the cost for the system.

The principal hazard in the use of high pressure cylinders is that the valve could be broken if the cylinder is dropped or knocked over. If this should happen, the cylinder could become a self-propelled projectile which could cause extensive damage and injury in a crowded shelter. It is necessary, therefore, that appropriate racks or other supporting devices be provided to prevent damage to the cylinders.

Chlorate candles have been of interest to the U. S. Navy for many years as a means of supplying oxygen in submarines. They consist of a mixture of sodium chlorate ($Na\ ClO_3$) with about 10 percent powdered iron, plus smaller amount of barium peroxide ($Ba\ O_2$) and powdered fiberglass. The mixture is cast or molded into the shape of cylinders of various sizes. When the upper end of the cylinder is ignited some of the chlorate decomposes and releases free oxygen. Some of the oxygen combines with the iron, producing heat to sustain the reaction. A small amount of chlorine is also produced. This combines with the barium peroxide to produce barium chloride and free oxygen. Also produced is iron oxide and sodium chloride. The latter vaporizes at the heat of reaction and produces

a smoke which, while non-toxic, would be a nuisance in a closed space. The gases should, therefore, be passed through a filter to remove the smoke.

The amount of oxygen produced depends on the size of the candle and is also a function of the diameter. The greater the diameter, the greater the oxygen production per pound of candle. For the smaller diameters more iron must be oxidized to maintain the required temperature and consequently less free oxygen is produced. Once the candle has been ignited the rate of oxygen production cannot be controlled but it can readily be extinguished.

The candles are not susceptible to spontaneous combustion and cannot be ignited by impact. They must, however, be kept scrupulously clean since impurities could produce toxic gases when ignited. They are stored in individual sealed cans until used and, if kept clean and dry, can be stored indefinitely.

They are available as self-contained units which include the ignition system and filters or as a separate candle to be burned in a special furnace. This furnace has provision for filtering the sodium chloride smoke and is recommended for use in a shelter even though it should be maintained by an experienced person.

The typical submarine candle is 6" in diameter, 12" high, weighs about 28 lb and produces about 100 cu ft of oxygen. Two of these are usually used at one time in the furnace and burn for $1\frac{1}{2}$ hours. They would supply oxygen for 100 men for two hours, leaving $\frac{1}{2}$ hour for the furnace to cool down and be readied for a new charge.

A smaller candle which supplies oxygen for about 48 man-hours, is available from Maywood Chemical Works. It is estimated that it would cost about $0.50 per man-hour for the candle and the burner. A larger, self-contained unit, available from MSA Research Corp., will liberate about 90 cu ft of oxygen in 50 minutes. The cost is estimated at between $0.65 and $0.70 per man-hour (66).

The temperature of reaction for the chlorate candles will vary from 1300°F to 1500°F. The heat liberated has been reported as between 40 and 100 Btu per cu ft of oxygen produced. The temperature of reaction and

heat liberated depend on the percentages of iron and barium peroxide used. The heat corresponds to an increase in the metabolic rate and must be considered in controlling the thermal environment in the shelter.

When the cost of metering devices is added to the cost of oxygen cylinders and the gas there is very little difference in the cost of oxygen supplied from cylinders or from self-contained chlorate candles. The two methods are also about equal on the basis of reliability and safety. On the basis of heat liberated, the cylinders have a decided advantage since they add no heat to the shelter environment. On the other hand, the candles would require much less storage space.

METHODS FOR REMOVING CARBON DIOXIDE

It has been pointed out that a limiting concentration of carbon dioxide will develop before the oxygen is critically depleted. A concentration of 1 percent or less for carbon dioxide has been recommended as a criterion for survival shelters. Table 3.1 gives a representative value for the respiratory quotient (RQ) as 0.83 cubic feet of CO_2 produced per cubic foot of oxygen consumed. If a criterion of one cubic foot of oxygen per person per hour is used, the corresponding requirement for carbon dioxide removal is 0.83 cubic feet per person per hour. Since the RQ varies for different people, the ratio may not be exactly 0.83.

There are a number of methods by which carbon dioxide may be removed from the air. These include:

A. Chemical absorption in a solid
   1. Superoxides
   2. Lithium hydroxide
   3. Baralyme
   4. Soda-lime
   5. Silver oxide

B. Liquid Absorbents
   1. Alkali hydroxide solutions
   2. Alkali carbonates
   3. Ethanolamines
   4. Electrolytic sulphate process
   5. Absorption with water

C. Adsorption
   1. Molecular sieves

2. Silica gel
3. Activated alumina
4. Activated carbon

D. Diffusion through a membrane

E. Freeze-out technique

The liquid hydroxide and carbonate solutions have some very desirable properties but the liquid requires much more storage space than the dry chemicals. The ethanolamines and electrolytic process require expensive and complicated equipment. It is estimated that it would require about 50 gallons per man-hour to absorb CO_2 with water.

The molecular sieves are too expensive for shelter use. Silica gel, activated alumina and activated carbon adsorb CO_2 in the same manner as molecular sieves but have much less capacity. Even though they are not as expensive, greater quantities would be required.

Diffusion through a membrane would require surface areas which would be completely impossible in a shelter, and freeze-out techniques require temperatures in the range of -200°F which, of course, could not be attained in a shelter.

Of the solid absorbents, the superoxides have already been discussed as sources of oxygen and rejected as being too dangerous to handle. Silver oxide is prohibitively expensive since it costs about $1.00 per ounce. This leaves soda-lime, baralyme and lithium hydroxide as possible CO_2 absorbents for shelter use.

Soda-lime (calcium hydroxide) has been used for many years to absorb carbon dioxide. It is used in hospitals for rebreathing apparatus. It used to have a tendency to cake and impede the flow of gas through it but newer mixtures include small amounts of sodium hydroxide and potassium hydroxide plus moisture which have helped to alleviate this problem.

The calcium hydroxide reacts with carbon dioxide to form calcium carbonate and water, releasing about 1055 Btu per pound of CO_2 absorbed. Since 0.83 cu ft is equal to about 0.1 lb of CO_2, this is about 106 Btu per man-hour.

Soda-lime may be spread out in a passive bed to absorb CO_2 from the air passing over it. In an emergency this could be merely a sheet or blanket with the soda-lime spread out on it, but it would be preferable to have trays to hold it prepared ahead of time. A canister of soda-lime with a blower to pass air through it would be the best method of using it. In this basis, it would require about 3 lb of soda-lime for each pound of CO_2 absorbed or about 8 lb of soda-lime per man day. The cost would be about $0.10 per man-hour plus the cost of the blower.

The dust of soda-lime is irritating to the eyes and mucous membranes and is somewhat difficult to control. Consequently, a filter to control the dust should be added to the canister-blower system and the use of passive beds should be avoided if possible.

Soda-lime will lose its capacity to absorb CO_2 if exposed to a moist atmosphere and must, therefore, be stored in a tightly closed container. Trays of soda-lime which might be prepared ahead of the time of use would also have to be tightly sealed.

Baralyme is also calcium hydroxide with about 20 percent barium hydroxide added plus trace amounts of dye and wetting agents. The wetting agents are added to reduce the tendency to dust and the dye indicates when the absorbing capacity is depleted by changing color.

The Baralyme can be used in a passive bed system. Although the dust is irritating, the wetting agents tend to control dusting. However a canister and blower would be preferred. When used in a canister-blower system, it would require about 10.5 lb of Baralyme per man-day. The cost would be about $0.16 per man-hour for the material, plus the cost of the blower. Heat generation would be about the same as for soda-lime.

Anhydrous lithium hydroxide reacts with carbon dioxide to form lithium carbonate and water. It has sufficient affinity for carbon dioxide so that it can be spread out on a sheet or blanket to absorb the CO_2. However the dust is very irritating, especially to the eyes and this method is recommended only as an emergency measure.

When used in a canister-blower system one pound of lithium hydroxide will absorb 0.92 lb of CO_2. The cost is between $4.00 and $5.00 per pound, or from $0.45 to $0.55 per man-hour, plus the cost of equipment. The heat released is about 1310 Btu per pound of CO_2 absorbed, or about 131 Btu per man-hour.

Any of the three solid absorbents, soda-lime, Baralyme, and lithium hydroxide, would be effective in controlling carbon dioxide in the shelter. Soda-lime would be the least expensive to use and lithium hydroxide the most expensive. Lithium hydroxide also generates more heat than the other two. All three are caustic and the dust is irritating. Baralyme may be somewhat easier to handle because of the reduced tendency to dust but all three should be used in a canister with blower rather than being spread out in passive beds. Table 10.1, taken from Reference 20, gives typical data for carbon dioxide absorbent canisters.

TABLE 10.1

TYPICAL WORKING DESIGNS OF CARBON DIOXIDE ABSORBENT CANISTERS

Persons Sheltered	Canister		Absorbent Weight Lb	Gas Vel. Fps	Estimated Pressure Drop, In. Water
	Dia. In.	Length In.			
10	13	17	75	0.25	0.4
100*	23	27	392	0.4	1.1

*Two units; specifications are for each unit.

CONTROL OF ODORS AND CONTAMINANTS

During periods when the shelter ventilation system is operating, the ventilation rates necessary to control the thermal environment will probably be sufficient to remove odors and contaminants to a satisfactory degree. The exception to this is during the winter weather when venitlation rates may have to be reduced to prevent the effective temperature from becoming too low. However, during "button-up" periods there is no air intake or exhaust, and other means must be found to control

noxious and possible toxic substances in the air. This could also be true during winter low ventilation periods.

Odors are produced by the human body from perspiration, urine, feces, and flatus. Other odors come from food preparation, decay of garbage, smoking, and from the toilet facilities. Contaminants can come from fuels, lubricants, refrigerants, chemical processes for air revitalization and other sources. Ammonia is produced from urine, sewage gas may contain large amounts of methane, hydrogen is produced from battery chargers (or from electrolysis of water) and smoking produces carbon monoxide.

In a crowded, unventilated shelter, body odors could be very unpleasant. However, the olfactory organs quickly become dulled and the odors are not noticed, except by persons who might enter from the fresh air, in which case the odors are almost nauseating. This has been reported by several investigators who have conducted human occupancy tests. There are, however, some exceptions to this, one of which is cigarette smoke. Although the odor of fresh cigarette smoke is not necessarily unpleasant even to non-smokers, stale smoke is unpleasant even to smokers. Cigarette smoke is also irritating to the eyes, and may contain carbon monoxide. Another exception is vomit, the odor of which has a strong psychological effect on many people.

Most of these odors can be masked by use of so-called air fresheners. Some of these merely "cover up" the odor with a stronger but more pleasant one. Others act on the olfactory organs to dull them. In general, masking of odors is not recommended for shelter use, since the odors are not removed from the air and the contaminants which often accompany them are also not removed. In addition, the odor of a dangerous substance such as ammonia or hydrogen sulfide might also be masked, thus eliminating one source of warning of its presence.

Activated carbon has been used as an adsorbant for poisonous or obnoxious gases for many years. It will adsorb most organic chemicals, except those of low molecular weight, and certain inorganic materials. It is best used in a canister and blower system or in a bed with air circulated through it with a blower. It

could be placed in series with a carbon dioxide scrubber and the same blower used for both.

A Molecular Sieve could be used instead of activated carbon since it will absorb practically the same materials. However, the cost would be much higher.

Some contaminants can be removed by combustion, but this would consume oxygen and add heat to the shelter.

Catalytic action can be used to remove some contaminants. This, however, requires special equipment in some cases and also adds to the heat load of the shelter.

It is estimated that about one-half pound of activated carbon would be required per person. This would cost about $0.33 not including the cost of a blower.

There are no particular problems in handling or storing activated carbon. However, during use it may become contaminated with toxic materials and should, therefore, be disposed of carefully.

The human senses do not provide a reliable means of determining oxygen or carbon dioxide concentrations. There will, of course, be physiological effects from excessive CO_2 or deficient oxygen, but it would be dangerous to rely on these as an indicator of improper concentrations. Consequently, it will be necessary to provide some type of instrument to measure and indicate carbon dioxide and oxygen concentrations in order for the shelter occupants to know when to supply more oxygen or replace the carbon dioxide absorbent.

Carbon monoxide gives no warning of its presence which can be detected by the human senses. It will, therefore, be necessary to provide a means of detecting and indicating concentrations of carbon monoxide. It would also be desirable to be able to measure concentrations of other toxic or explosive gases which might be present, such as ammonia, hydrogen, hydrogen sulfide, methane or fuel vapors.

Fortunately there are available commercially simple, reliable instruments for all of these purposes at relatively low prices. Some of these are manually operated and some, at higher cost, are power operated. Many of the power operated instruments are more or less automatic in their operation. However, for economy and

reliability the manually operated instruments would probably be the best choice for shelter use.

Instruments of this type have been developed for use in mines and for industrial hygiene work. Therefore the most likely source of obtaining them would be through mine and industrial supply companies.

CONTROL OF THERMAL ENVIRONMENT

In a closed shelter there will be no ventilation air for cooling purposes. The only natural method for removing heat will be through the shelter walls to the surroundings. It may be assumed that a shelter for protection against mass fires will be underground and, therefore, the heat sink will be the surrounding earth.

Under conditions of low earth temperature and relatively large shelter surface area per person, there may be enough heat transferred through the walls to maintain a tolerable effective temperature. However, there would be no moisture removal except by condensation on the walls if the wall temperature was below the dew point.

In group or community shelters, the shelter surface area would probably not be sufficient to transfer enough heat to maintain the effective temperature below 82°F. It is, therefore, probably safe to assume that some form of mechanical cooling will be necessary during the "button up" period. Not only will there be no ventilation air for cooling purposes, but there also will be the added heat from the oxygen producing system (except compressed gas cylinders), the carbon dioxide removal system. the heat of adsorption from the contaminant removal system and the heat liberated by condensation of water vapor if desiccants are used.

If a mechanical cooling system is to be used, it probably will be designed to operate over the entire term of occupancy of the shelter, rather than on the basis of a 24-hour closure period, and the methods presented in the previous chapters can be used for design purposes.

However in a closed shelter there could well be a question concerning the availability of power. If public utility power is not available, as well may be

the case, the shelter would have to depend on its own power capability. All of the practical auxiliary power systems depend on combustion processes and combustion air intakes will probably have to be sealed as well as the ventilation air intakes. Cooling air for the power system also would not be available. Consequently there is a strong possibility that the auxiliary power system could not be operated during buttoned up operation.

So far as is known there is no practical power system which will operate as a completely closed system, other than storage batteries, although fuel cells hold considerable promise in this respect, and research has been proposed on closed-cycle internal combustion engines. This fact provides another argument in favor of a well water cooling system since it would be possible to provide at least a minimum amount of cooling capacity by manual pumping in many cases.

CHAPTER XI

PROTECTION AGAINST HAZARDS IN ADDITION TO FALLOUT

The objective of the current civil defense program is to identify or develop a sufficient number of fallout shelter spaces to protect all of the population of the United States wherever they may be (home, work, school) from the effects of radioactive fallout. Since early fallout covers a larger portion of the population than do other effects of nuclear weapons, protection against fallout radiation is a logical starting point in a defense program.

When fallout shelters with habitable environments have been provided, additional protection against other weapons effects can be considered. One way of providing these shelters would be to increase the protection capabilities of existing fallout shelters. Consequently, it may be desirable to provide for this increased protection in the design of the fallout shelter.

In addition, the pattern of possible nuclear attack cannot be predicted and it is possible that a fallout shelter could be in the fringe areas of blast effects. Therefore, any protection capability which can be incorporated in the shelter design would be an advantage.

A thorough consideration of the design of blast shelters is beyond the scope of this discussion. However, a brief consideration of some of the aspects of blast protection of mechanical systems is worthwhile.

A blast resistant shelter is defined as one which has been designed to resist a specified overpressure and all the concomitant weapons effects, so as to insure a very high probability of survival of the occupants when the shelter is subjected to that overpressure. The probability of survival would be less for weapons effects associated with overpressures above design values. The extent to which the shelter continues to offer protection above design values is a function of structural design, weapon yield and environmental conditions.

Because of the nature of the overpressure distribution associated with a nuclear detonation, far greater land area is exposed to overpressures less than, say, 25 psi

than from 25 psi to ground zero. This is not to say that more people, or shelters, would be subjected to lower overpressure levels, since this would depend entirely on the kind of attack an enemy might mount. It does suggest, however, that the greatest probability for reducing significantly the lethal range of the weapon is at the lower end of the overpressure scale.

It will be noted that in defining a blast-resistant shelter, it was stated that such a shelter would protect against initial nuclear and thermal radiation as well as blast. This is due to the fact that a shelter within the range of the blast overpressures will also be in range of the radiation effects. A shelter receiving 100 psi overpressure would be within the fireball for weapons of 0.5 megaton or larger.

Table 11.1 summarizes the relative effects of blast overpressure, initial nuclear radiation, and thermal radiation at various distances for various size weapons. The height of burst for each case is such as to maximize the effects. Thus, the data in the table are the maximum values which might be expected at the indicated range. The initial nuclear radiation dosages are not given for distances of 5 miles or more since they are extremely small even for a 10 megaton explosion. The data is taken from the Effects of Nuclear Weapons, Chapter XII. (3)

In interpreting the data of this table, it should be kept in mind that a blast overpressure of 2-3 psi will severely damage most residential structures and about 10 psi will cause serious damage to almost any conventional structure. A thermal radiation exposure of about 7 cal/sq cm will cause second-degree skin burns and ignite kindling materials. The initial nuclear radiation has a much greater energy level than the residual gamma

TABLE 11.1

WEAPONS EFFECTS FOR AIR BURST WITH MAXIMIZED RANGES

Distances From Ground Zero	Explosion Yield 1 KT	10 KT	100 KT	1 MT	10 MT
1/2 Mile					
Overpressure (psi)	4.1	13	46	**	**
Thermal Radiation (cal/cm^2)	3.8	38	380		
Initial Nuclear Radiation (rems)	670	6700	76000		
1 Mile					
Overpressure	1.5	4.5	14	**	**
Thermal Radiation	0.9	9.1	91		
Initial Nuclear Radiation	9.1	91	1100		
2 Miles					
Overpressure	1.0	1.7	5.0	16	**
Thermal Radiation	0.2	2.1	21	210	
Initial Nuclear Radiation	---	0.2	1.9	35	
3 Miles					
Overpressure	---	1.0	2.8	8.6	29
Thermal Radiation	---	0.9	9.0	90	900
Initial Nuclear Radiation	---	---	---	<1.0	2.6

TABLE 11.1
(continued)

WEAPONS EFFECTS FOR AIR BURST WITH MAXIMIZED RANGES

Distances From Ground Zero	Explosion Yield				
	1 KT	10 KT	100 KT	1 MT	10 MT
<u>5 Miles</u>					
Overpressure	---	<1.0	1.4	4.1	13
Thermal Radiation	---	<1.0	3.0	30	300
<u>10 Miles</u>					
Overpressure	---	---	<1.0	1.5	4.5
Thermal Radiation	---	---	<1.0	6.6	66
<u>20 Miles</u>					
Overpressure	---	---	---	<1.0	1.7
Thermal Radiation	---	---	---	1.4	14
<u>50 Miles</u>					
Overpressure	---	---	---	---	<1.0
Thermal Radiation	---	---	---	<1.0	1.7

** Inside or close to fireball.

---Value too small to be significant

radiation and consequently 18 inches of concrete or 26 inches of earth are required to attenuate it by a factor of 10 (as compared to 8 inches of concrete or 12 inches of earth for residual radiation). A dose of 100 rems would have little or no immediate effect on exposed persons and many persons receiving doses of up to 200 rems would not be greatly affected. At about 400 to 500 rems all persons exposed would become sick and require medical care. Approximately half of these would recover. A whole body dose of 1000 rems would cause sickness within 4 hours and death within 2 or 3 weeks for almost everyone exposed.

These data indicate that, when designing a shelter to resist blast overpressures, it will also be necessary to consider the effects of the initial nuclear radiation and the thermal radiation. Shielding against the nuclear radiation is a function of the basic shelter structure and, as such, is the responsibility of the architect or structural engineer who designs the shelter. This is also true for the degree of blast resistance which the shelter will afford. Normally the engineer designing the mechanical systems will not be concerned with the design aspects of the structure itself except insofar as they affect the mechanical components. There may be cases where one person would design both the structure and the mechanical systems but that person would of necessity, have previous training in structural design. Therefore no consideration will be given here to the problems involved in the design of the basic shelter structure.

The mechanical engineer will, however, be concerned with the effects of the thermal radiation since the external components of the mechanical systems, such as ventilation valves, will be exposed to very high thermal radiation levels. Laboratory tests, as well as experiments at nuclear test sites indicate that exposed components of shelters can be protected against thermal radiation by (1) highly reflective coatings, (2) use of refractory materials, and (3) coatings of materials with high latent heat of fusion and vaporization (69).

For blast shelters with high degree of blast resistance the thermal exposure will be sufficiently large so that the only means of protecting the exposed portions of the mechanical systems appears to be by thick coatings of materials which use the process of ablation.

The process of ablation is one where the protective material is removed by melting and vaporizing, or sublimating, and is carried away as a gas. The heat transfer to the surface is reduced by the heat necessary to sublimate the material and, in addition, some of the thermal radiation is absorbed by the gaseous products of ablation. However this conclusion is based only on theoretical analysis since no laboratory tests have been able to reproduce the conditions to be expected from a full scale weapon (69).

At lower levels of blast resistance refractory or reflective coatings may be sufficient protection against the effects of thermal radiation.

In considering the protection of mechanical systems against blast effects, the level of blast protection necessary will be determined by the structure. It would be useless to design systems to resist overpressures greater than could be withstood by the structure. At the same time, mechanical systems with less blast resistance than the structure will reduce the degree of protection afforded by the shelter. Blast protection is expensive and overdesign cannot be justified economically.

It is not necessary that the structure suffer total collapse in order for it to provide inadequate blast protection. If it is damaged so as to open cracks in the structural shell, the occupants would be exposed to subsequent radiation. Pieces broken from frangible materials can cause "missile damage" to the occupants or equipment. A pressure buildup on the interior due to inadequately protected openings could result in injury or death even if the structure did not fall. Openings which might permit such a pressure build-up might be leaks around doors or hatches, cracks in the structure, ventilation or exhaust ducts, or sanitary vents.

From the standpoint of economy, it is often desirable to design a structure which will yield under blast loading and permit deflections beyond the elastic limit without undergoing serious damage or collapse. It must be accepted that there is a probability of deflection and partial damage to the structure and this must be taken into account in the design of mechanical systems.

The mechanical systems must be able to accommodate differential movements and must be protected against relative motion between the structure and equipment.

At any point where service lines pass through the shell of the structure, flexible connections should be provided to allow for relative motion between the structure and the ground. Such service lines would include water and sanitation piping, fuel lines, and electrical conduit. In addition, water lines should be provided with a check valve at the point where they enter the structure and sanitation discharge piping should include backpressure valves.

Mechanical equipment should be shock mounted and clearance provided between the equipment and adjacent objects in order to accommodate relative displacements. The requirements for adequate shock mounting depend on the strength of the shock wave, the fragility of the equipment, the subsurface depth of the structure and the physical properties of the surrounding materials. There are two types of shock: air induced shock and lateral ground shock. Strong blast overpressures may cause high momentary accelerations and large displacements of the structure. Hence conventional vibration mounting may be quite inadequate. It is apparent the flexible connectors should be provided on fuel and water lines and electrical conduit to the equipment.

In some cases ventilation air ducts can be installed in protective concrete envelopes integral with the floor or roof slab in order to eliminate relative motion between the ducts and the slab. In other cases the ductwork can be suspended and provided with flexible connectors in order to accommodate the relative motion.

Lighting fixtures may be pendant mounted and equipped with plexiglass or lucite diffusers. The use of incandescent lights should be avoided since the tungsten filaments are vulnerable to shock. However locking devices should be provided to hold fluorescent tubes in their fixtures.

In a blast shelter, all openings into the shelter must be equipped with blast valves, or blast doors in the case of entrance ways. Blast valves would be required at the ventilation intake and exhaust, on sanitation vents, and on air intake and exhaust openings for the

power system. These valves must be provided with means for manual closing and opening from within the blast protected space. In addition they should be blast or sensor actuated for automatic closure. The sensing device may react to heat, light, radiation or pressure, resulting from a nuclear explosion and must be capable of distinguishing between natural or man-made signals and the signal characteristic of a nuclear detonation. The remote sensor must be located at sufficient distance from the valve to allow time to transmit the signal and for the valve to close before the blast wave reaches the valve. Heat, light and radiation travel at the speed of light and would reach a sensor before the pressure wave. Therefore pressure sensors must be located at a greater distance from the valve than the other types in order to insure sufficient closing time.

Blast valves used on air intake systems equipped with filters should limit the pressure build-up during the closing cycle to 2 psi or less. A blast pressure of 2 psi will cave in ordinary panel type filters and severely reduce the efficiency of even the better military specification types. Such a pressure would not cause direct traumatic injuries to human beings in the shelter but could result in secondary injuries by their being knocked down or being struck by flying objects resulting from breakage in the shelter. Therefore, the passages between the blast valve and the filter should be constructed with expansion chambers or 90 degree bends to attenuate the pressure to 1 psi or less. A perforated metal plate with 10 percent open area installed ahead of the filters would reduce pressure from 2 psi to 1 psi.

The leakage rate of blast valves, measured by the overpressure developed in the shelter in relation to the incident overpressure, is kept at a low design value to avoid damage to filters and other fragile parts of the ventilation system since the human tolerance to overpressure is relatively high. The necessity for maintaining a low leakage rate sharply increases the cost so that the air filters and low-cost blast valves are generally incompatible. Thus the conclusion that air filters are unnecessary for fallout protection improves the prospect for the development of low-cost blast closures. If, in addition, communications and warning systems are such as to give warning time

sufficient to allow the use of manually operated valves, the cost could be further reduced.

Blast values installed in exhaust lines or direct intake lines are required to limit pressure build-up to 5 psi. This would also require the use of 90 degree bends or expansion chambers to attenuate the pressure reaching the shelter interior.

It is obvious that all blast valves must have sufficient corrosion resistance to insure that they will remain operable at all times. Valves used on engine exhausts must be resistant to the high temperature and corrosive effects of the exhaust gases.

There are several types of blast closure devices available and new ones are constantly under development. A comprehensive consideration of the various operating principles and characteristics is, however, beyond the scope of this discussion.

When a blast wave strikes a surface which is not parallel with the direction of travel, a reflected pressure is produced. The magnitude of this reflected pressure depends upon the angle between the surface and the direction of the blast wave. In order to reduce the effects of reflected pressure, blast valves should be installed with movable heads flush with the duct through which the blast wave will travel. Placing the valve below the surface of the ground will reduce reflected pressures as well as attenuate the overpressure.

PROTECTION AGAINST CHEMICAL AND BIOLOGICAL CONTAMINATION

STUDIES INDICATE THAT THE THREAT TO THE UNITED STATES POSED BY CHEMICAL AND BIOLOGICAL AGENTS IS RELATIVELY LESS SIGNIFICANT THAN THAT POSED BY THE NUCLEAR ONE. CHEMICAL AGENTS ARE NOT CONSIDERED A MAJOR STRATEGIC THREAT AS THEY ARE EFFECTIVE MAINLY IF USED AGAINST TACTICAL TARGETS OF LIMITED AREA. ALTHOUGH THE POSSIBILITY OF EMPLOYMENT OF BIOLOGICAL AGENTS AGAINST THE U. S. POPULATION CENTERS CANNOT BE RULED OUT, NEITHER A CHEMICAL NOR BIOLOGICAL THREAT AGAINST THE CONTINENTAL UNITED STATES WARRANTS, AT THIS TIME, THE ATTENTION AND PRIORITY GIVEN TO DEFENSE AGAINST THE EFFECTS OF NUCLEAR WEAPONS. HOWEVER, RESEARCH ON METHODS OF DETECTING,

IDENTIFYING, REPORTING, ANALYZING, AND DEFENDING AGAINST BIOLOGICAL AGENTS WILL CONTINUE WHILE THE POTENTIAL THREAT IS KEPT UNDER CONSTANT REVIEW.

Agents of chemical or biological warfare are not produced by the detonation of a nuclear weapon. However, it is possible that a nuclear attack could damage chemical manufacturing or processing plants and thus release contaminating agents into the environment. Protection against these types of contaminants involves many of the same techniques which are effective against radiological contaminants. Therefore, it is worthwhile to give brief consideration to the modifications which could be made to the protective structure to provide the additional capability to protect against chemical and/or biological contamination.

Chemical warfare agents are solids, liquids, and gases which produce lethal, injurious, irritating or psychological effects. They are spread in the form of vapors, particulates or liquid droplets. The poison gases may be classified as: (1) blister agents, such as mustard, nitrogen mustard and lewisite; (2) choking gases such as phosgene and diphosgene; (3) vomiting gases such as Adamsite, and dithenylchloarsine; (4) blood gases such as hydrogen cyanide, cyanogen chloride and arsine; (5) harassing agents such as acetophenone; (6) nerve gases; and (7) psychochemicals (53).

All of the known toxic gases, except the nerve gases and psychological gases, can be detected by the human senses. In addition, there are available chemical agent detector kits and automatic gas alarms. The alarms will also detect the known nerve gases.

Biological warfare agents are viruses, living organisms or their toxic products and there are no sensing or warning devices presently available which will detect them. They can be identified but this requires collecting samples and growing cultures, which takes anywhere from several hours to several days.

Protection against chemical and biological agents consists of providing air that does not contain these agents. This means supplying air that has not become contaminated or removing the contaminating agents from the air. Methods which could be used might include one or more of the following:

1. Remove contaminating agents from the incoming air by filtering and/or adsorption;

2. Recirculate the air inside the shelter through filters and/or adsorbers;

3. Seal the shelter completely and supply revitalized air by methods summarized in Chapter X;

4. Provide each occupant with a self-contained device such as a gas mask;

5. Provide each occupant with an air-storage device such as SCUBA apparatus;

6. Provide individual masks or mouthpieces connected to a central source of uncontaminated air.

Although any or all of these methods could be used, there are obvious objections to some of these. Gas masks or SCUBA apparatus may be suitable for short periods of time, or for persons who might have to leave the shelter to perform vital duties, but they would not be practical for periods which might last for days or even weeks. The central source of air with individual masks would have the same limitations. Complete closure of the shelter is possible and may be desirable, but it involves the necessity of supplying oxygen and removing carbon dioxide and of controlling the thermal environment. Recirculating the inside air is probably desirable in almost all cases, but as the only means of controlling airborne contaminants, it may be less than 100 percent effective, since the air entering the shelter is still contaminated.

It would appear that the best approach would be to remove the contaminating agents from the incoming air before it enters the shelter. Recirculation of the air can be added to this in order to provide additional protection against the accidental or intentional release of chemical or biological agents inside the shelter. It is also desirable to maintain a small positive pressure inside the shelter to prevent the leakage of contaminated air through cracks or imperfectly sealed openings.

The best method of removing toxic gases from the air is by adsorption with granulated activated charcoal. It should be noted that carbon monoxide, ammonia, and similar gases are not war gases and will not be adsorbed by activated charcoal, unless it has been specially treated. Activated charcoal will vary in its physical and chemical structure depending on the raw material, methods of manufacturing, and impregnation with various additives. Its performance in removing various gases and vapors will vary with the variation of the above factors.

Biological agents consist of bacteria, viruses and other micro-organisms which are particulate in nature. Thus a high efficiency particulate filter will remove them. This filter should be placed ahead of the gas adsorber since it will collect not only the biological particulates but also aerosolized toxic agents. These aerosols would be held until they vaporized and were adsorbed in the gas filter. In aerosol form, they could pass through the adsorber without being removed.

Prefilters of the medium efficiency type should be used ahead of the high efficiency particulate filters to collect larger particles and extend the useful life of the high efficiency filter. This would be especially true in an area where high concentrations of fallout or inert dust might be expected.

The prefilter would probably be a disposable panel type using either dry or viscous impingement. The particulate filter consists of a special filter medium, developed by the U. S. Army Chemical Corps, which is folded into pleats and sealed in a wood frame. The pleats may vary in depth from 5-3/4 inches to about 11 inches depending on the filter. Each filter is tested and must measure a penetration of less than 0.03% (greater than 99.97% efficiency) on particles of 0.3 micron.

Gas filters consist of specially treated activated carbon to remove or inactivate poisonous gases or vapors which penetrate the particulate filter. Special controls and precautions are exercised during their manufacture because of the degree of protection required. A mixture of coarse and fine carbon granules is packed tightly into perforated metal trays. The filling is done under pressure and vibration to insure a gas-tight

barrier between the carbon and the sides of the tray and to prevent settling of the carbon even after rough handling. Obviously if the carbon were to settle voids would be created which could allow the gas to leak through. Extremely rigid standards of quality control and testing are maintained on these filters.

The prefilter, particulate filter and gas filter may be purchased separately or as a unit consisting of the particulate and gas filter only, or all three. It is also possible to obtain a unit consisting only of the prefilter and particulate filter but this would provide only radiological and biological protection. The complete CBR filter unit is also available with the blower and motor drive, either electric motor driven or gas engine driven, or with manual drive.

The maximum capacity of each filter unit, in cubic feet per minute, is specified and should not be exceeded. If greater capacity is needed, two or more units should be installed in parallel in order to avoid excessively high resistance to air flow and excessive pressure drops across the filter.

When the filter is located inside the protected structure it should be installed on the suction side of the blower so that the pressure in the filter and inlet duct will be less than that of the filtered room air. Thus only filtered air can leak into the duct in the event of leaking joints. If the filters are placed downstream from the blowers, contaminated air flowing from the blower to the filter would be at a pressure greater than room air and leakage of contaminated air from the duct to the room could occur.

It is likely that protection against chemical and biological agents would be provided in a shelter for vital operations and personnel. Such a shelter would probably provide blast protection also. In this case, the incoming air would enter through the blast closure device, a plenum or expansion chamber, a prefilter, a particulate filter and then through the gas filter. The series of protective devices will provide a resistance of 2-4 inches of water when the filters are clean and from 4-6 inches when the filters are loaded. It can thus be seen that power will be necessary for the blowers.

If an air conditioner is used, the incoming air, after leaving the filters, would pass through the air conditioner and then to the sheltered space. It should leave the shelter through the entrance air lock in order to scavenge the entrance system. An antiback-draft valve and blast closure would be installed in the exhaust duct to protect against backflow due to wind gusts or blast overpressures.

The entrance system for a CB protected shelter should include an airlock for entrance and exit, and a decontamination room which includes showers and a means of disposing of contaminated clothing and equipment. Air should flow through the decontaminating chamber at not less than 15 to 20 feet per minute, counter to the movement of the entering personnel.

In order to prevent air leakage into the shelter through the building walls and openings, the shelter should be pressurized. The lowest pressure at the air locks should be at least 0.3 inch of water which will be sufficient to overcome the pressure of a steady 25 mph wind (72). The maximum pressure required will be determined by the arrangement of the shelter facilities. The pressure should drop 0.1 inch of water (maximum) for each chamber leading from the main shelter area to the air lock. Thus if there is a main shelter, a decontamination room and an air lock, the pressure in the main shelter should be regulated at about 0.5 inch of water, about 0.4 inch of water in the decontamination room and 0.3 inch of water in the air lock.

It is possible to build an unpressurized protective shelter but it must be absolutely airtight. This requires the complete sealing of the shelter, keeping in mind that many common building materials are permeable to gas. Also, some means of entrance and exit must be provided which will not result in contaminants entering the shelter. Consequently, unpressurized operation is not practical or recommended.

Recirculation of the ventilation air will reduce the capacity required for the intake system. If air conditioning is available, the fresh air intake capacity required is only enough to supply the necessary oxygen, or about 3 cfm per person. Without air conditioning, the capacity will be determined by the necessity for controlling the effective temperatures.

There are several possible arrangements for air recirculation.

1. Recirculated air passes through the air conditioner only and make-up air enters through the CB filters.

2. Recirculation through a particulate filter and air conditioner only and make-up through the CB filters.

3. Both recirculated and make-up air pass through the complete CB system.

4. Recirculated air passes through the separate particulate filter and commercial gas filters and mixes with CB filtered air before going to the air conditioner.

The third method would provide maximum protection against external contaminants and those which might be regenerated within the shelter. The fourth method would probably not provide protection against internally generated toxic gases but would remove odors from the recirculated air.

Air which has passed through the toilet areas should not be recirculated without being filtered for odor removal. Air from the decontamination areas should not be recirculated without passing through the complete CB system.

Since the threat of chemical or biological agents is much less significant than nuclear weapons effects, available finances for shelter can probably provide greater life saving potential if applied to other types of protection such as increased levels of fallout radiation protection, increased ventilation capability or some blast resistance. Therefore designers of shelter facilities would be well advised to avoid designing elaborate chemical and biological protection systems until they have assured themselves that the money could not be better used for these other types of protection.

CHAPTER XII

SELECTION OF SYSTEM COMPONENTS

The development of additional shelter spaces is concentrated on the incorporation of dual use shelter in new buildings at minimum cost. In this context, there would seldom be any justification for the design of special mechanical systems for the shelter area. The features discussed in this chapter would be desirable in any shelter, and could be incorporated at the option of the owner, but this is not compatible with the austere shelter program nor the slanting of buildings at little or no cost. The following discussion, therefore, applies for the exceptional situation where the cost of special mechanical systems can be justified and is acceptable to the owner of the facility.

Once the various aspects of the problems involved in the design of mechanical systems for fallout shelters have been analyzed and the system requirements have been determined, the selection of the system components and configuration can be made of accordance with the following general objectives (2, 20):

1. To protect the occupants of the shelter and the equipment from weapons effects and fire effects to a degree that is consistent with potential capabilities of the shelter;
   a. Maintain radiation barriers inviolate by providing shielding at points where ducts penetrate the structural shell;
   b. Provide a weather proof air intake fixture that tends to exclude fallout particles, and locate this fixture at a safe distance from combustible materials and above the ground turbulence layer;
   c. Avoid contamination of interior spaces, equipment rooms and entryways by radioactive particles and combustion gases from fires or fuel-burning equipment;
   d. Provide blast closures or attenuators for blast-resistant shelters;
   e. Provide filters for purifying the fresh air to a degree consistent with the intended use of the shelter; shield occupied spaces from the air filters;

f. Consider the use of life support systems for suitable closed shelters located in a potential fire area;
g. Consider the requirements for shock-mounting equipment in blast-resistant shelters.

2. To maintain a tolerable physical environment;
3. To prevent or minimize condensation of moisture on interior surfaces;
4. To avoid awkward duct connections and the resultant head losses and noise;
5. To re-use waste air from the ceiling level of occupied spaces for scavenging service areas such as equipment rooms, toilets, and entryways;
6. To facilitate operation, maintenance and repair of all equipment;
7. To provide system flexibility for accommodating seasonal changes and variations in physical activity;
   a. Reduce the quantity of fresh air in cold weather or temper the air with waste heat to avoid over-cooling;
   b. Provide mixing dampers and plenum for partial recirculation of the air in order to maintain air motion and to temper the air supplied to occupied spaces;
   c. Provide means for adjustment of air distribution to correct objectionable drafts and to balance the system according to space usage, that is, for sleeping and recreation;
8. To anticipate and facilitate probable future improvements or changes in shelter capabilities;
9. To achieve optimum cost-effectiveness, that is minimum cost consistent with adequate performance for the integrated shelter system.

It is possible, indeed probable, that it will not be practical to attain all of these objectives in any given shelter system. Certainly in a small, family shelter the ventilation system would be minimal and offer very little in the way of flexibility, air

recirculation, high efficiency filtration, blast closures, etc. It would probably consist of little more than an intake fixture, duct connections to a manually operated blower, and an exhaust outlet.

For larger shelters the system may be more sophisticated and have provisions for meeting many of the objectives listed.

The components for a near-minimal forced ventilating system for an underground fallout shelter are listed in Reference 20 (also in Reference 2).

1. <u>Weatherproof intake fixture for fresh air.</u>
   This may be a hood of the mushroom type with threaded connection for attachment to the intake duct, which terminates 2 ft above grade. The hood has a low inlet velocity to promote gravity separation of coarse particles, and a screened opening to exclude leaves and vermin. The fixture is located some distance from the shelter and adjacent wood-frame building. In large systems, other types of intakes may be utilized.

2. <u>Air intake duct between hood and plenum.</u>
   This duct is made of steel or abestos cement pipe and is buried underground. This construction provides beneficial heat exchange with the earth under extreme conditions during summer or winter.

3. <u>Fresh air plenum and filters.</u>
   The plenum should be in or adjacent to the equipment room, may be made of solid concrete masonry units, may have an access opening into the adjacent entryway, and should contain the supporting framework for the air filter panels. The filter media may be flame-resistant pleated glass fiber mats supported in a metal cell by pleated wire screen on both sides. Support of the filter media on both sides is particularly desirable in blast shelters.

4. <u>Duct connections to fan inlet.</u>
   This duct may be of flexible, wire-reinforced, impregnated glass fiber tubing.

5. <u>Blower with combination drive.</u>
   The blower is a single-inlet, radial blade centrifugal type (See Chapter 40 of the 1963 ASHRAE Guide and Data Book). With constant-speed motor drive, the fan is assumed to have a capacity of 15 cfm per occupant against a static pressure of 1.5 in of water. The alternative manual drive is bicycle type. Class II construction may be selected if there are plans for upgrading the shelter to provide blast protection.

6. <u>Distribution duct and diffusers.</u>
   This duct supplies air through adjustable diffusers. The air traverses the shelter before being exhausted through the equipment room, toilets and entryway.

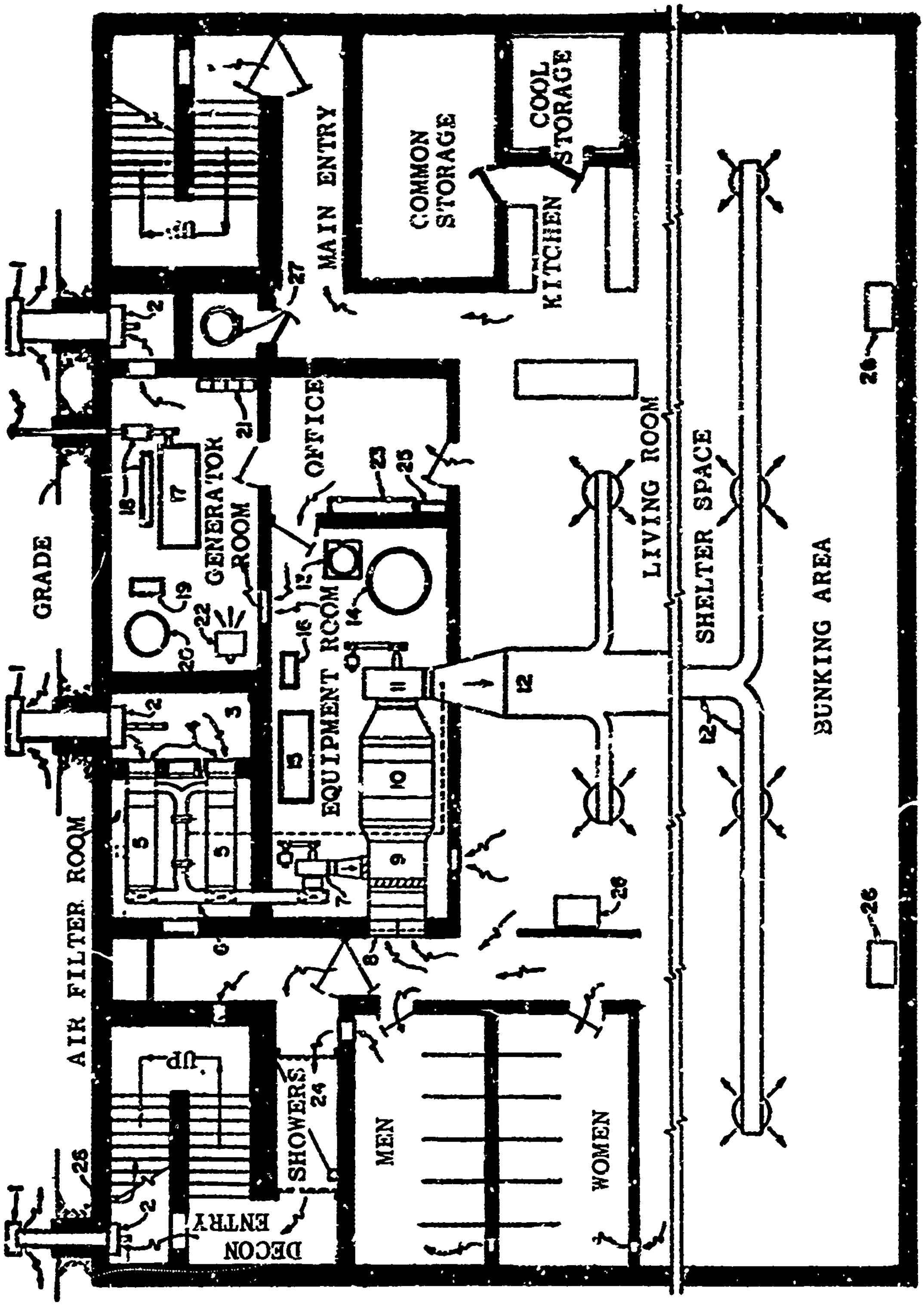
7. <u>Recirculating duct and grill.</u>

8. <u>Fresh and recirculated air mixing dampers.</u>
   The recirculating duct and mixing dampers provide for manual adjustment of the fresh air quantity without reducing the amount of air supplied to the shelter.

9. <u>Provisions for discharge of waste air.</u>
   This includes openings with adjustable registers for exhausting waste air to the outside through the equipment room, toilets and entryway and an exhaust duct connection to a weatherproof exhaust hood above the toilets. The exhaust hood has a screened opening. The flow of air through the exhaust openings can be restricted to pressurize the shelter. In warm weather, waste air is taken from the shelter at ceiling level.

A much more extensive system is illustrated in Figure 12.1. This figure has been reproduced from Reference 74 and the following description of the system is that of the author of the reference, Frank C. Allen, who also wrote Reference [illegible] and assisted in the preparation of Reference 20.

"In the configuration shown in Figure 12.1, utility and service areas are grouped for ventilation in sequence by waste air leaving the shelter. The numbered items may be identified as follows:



UNDERGROUND COMMUNITY SHELTER
ENVIRONMENTAL CONTROL SYSTEM
CONFIGURATION & AIR FLOW DIAGRAM
Figure 12.1

"1. Weatherproff hoods of the mushroom type for intake and exhaust air. If the air intake fixture is designed for low entering air velocity (less than 200 ft/min), coarse particulates having a higher terminal velocity of fall would be separated by gravity from the fresh air supply.

"2. Automatic blast closures for shelters planned for blast resistance.

"3. Fresh air intake plenum or expansion chamber.

"4. Fresh air filters or prefilters. For example, these may be panel filters with a dry or viscous-coated pleated media of fine bonded glass fibers supported in a metal frame by pleated wire screen on both sides.

"5. Gas-particulate filters for protection against chemical and biological agents in shelters planned for this purpose.

"6. Fresh air ductwork with by-pass for the gas-particulate filters. The space between the two by-pass valves or dampers is pressurized by a pipe connection to the main fan discharge to assure that any valve leakage is uncontaminated air.

"7. Fresh air blower with electric motor drive. Since this blower pressurizes the space and must be capable of operating against a rather high system resistance it air flow is restricted by gas-particulate filters and blast valves, Class II construction may be indicated.

"8. Grilled opening for recirculated air. Behind the grill are optional prefilters and activated charcoal filters for odor control.

"9. Mixing plenum with adjustable dampers for fresh and recirculated air.

"10. Air conditioning chamber with cooling and heating coils. Cooling coils use well water and heating coils use waste heat from the

engine-generator.

"11. Main fan with electric motor drive.

"12. Air distribution ductwork with diffusion outlets. If cooling and dehumidifying equipment is not provided, an air supply system which introduces all of the air at the end of the occupied space most remote from the exhaust openings will probably result in minimum discomfort during warm weather.

"13. Well and pump for potable and cooling water. A charging well for waste water may be desirable. If well water is not available, other means must be substituted for cooling the shelter and equipment. Heat transfer apparatus for blast shelters should be blast resistant if installed outside a protective structure.

"14. Hydropneumatic tank for pressure water system.

"15. Optional package water chiller for alternative or supplementary use. This item may be required in hot humid climates where cool well water is not available.

"16. Chilled-water circulating pump. This item may be an integral part of the package water chiller.

"17. Emergency engine-generator set cooled by a heat exchanger or, alternatively, by a remote radiator. The fuel storage tank is not shown.

"18. Heat exchanger and muffler for engine cooling and waste heat recovery.

"19. Hot water circulating pump.

"20. Hot water storage tank.

"21. Batteries for starting engine and for emergency lighting.

"22. Recirculating unit cooler for generator room.

"23. Control cabinet for functional control apparatus.

"24. Decontamination facility for entry of contaminated personnel.

"25. Cabinet for detection and test instruments.

"26. Portable manually-operated life-support systems for a maximum of 24-hour sealed operation.

"27. Incinerator for combustible waste materials.

"28. Sewage pump and pump below stairs.

"It should be emphasized that this illustrative system is not representative of minimum requirements. In a fallout shelter with a simple system for cooling by ventilation with outside air, many of the items would be omitted--but the basic features of the ultimate plan could be retained."

For most applications centrifugal fans with Class I construction will probably be adequate. However, Class II construction would be indicated if the system resistance to air flow is high, as would be the case if blast closure valves or gas-particulate filters are included or if the shelter is to be pressurized. According to the classifications of the Air Moving and Conditioning Association (AMCA) both Class I and Class II fans are standard duty types, the principal difference being in the blade tip speeds and the static pressure. Class I fans use blade tip speeds up to 10,000 ft per min and static pressures up to 5 inches of water. Class II fans use blade tip speeds up to 14,000 ft per min and static pressures up to 10 inches of water. Generally speaking, if the required static pressure exceeds about 4.5 inches of water, Class II construction should be used.

Ducts used for air distribution may be standard rectangular, round or oval in cross-section. However, oval duct is considerably more expensive than the other two types and probably should not be considered.

Round duct has an installed cost of about 66% of that for rectangular duct with an aspect ratio* of 1:1 and as the aspect ratio of the rectangular duct increases the cost also increases. The round duct also has the lowest operational cost (power consumption) for a given cross-sectional area and flow rate (75).

The only advantage to be gained by the use of the rectangular duct would be increased headroom, with overhead installation of the distributing system. This is hardly sufficient to offset the lower installation and operating costs for round duct. Consequently round duct would normally be used in a shelter. In a dual purpose shelter, of course, the requirements for normal operation will determine the type of ducts to be installed.

In general, air velocities in the ducts should be held as low as possible to limit friction losses and reduce noise. However, lower velocities require larger ducts which occupy more space and increase installation costs. In conventional systems maximum duct velocities are limited to 1200 fpm for residences, 1600 fpm for public buildings, and 2200 fpm for industrial buildings. Velocities of about 2000-2200 fpm in main ducts and 1500-1600 fpm in branch ducts might be a suitable assumption for initial design purposes in a fallout shelter. Since the required fan horsepower increases approximately as the square of the velocity, it may be desirable to decrease these velocities in order to conserve power, especially if the system may be operated on auxiliary power or manually.

In a single purpose shelter the problem of noise in the ventilation system should not be a determining factor in selecting duct sizes and air velocities. The noise in the ducts and/or diffusers would be a steady background sound and would probably not be objectionable to the shelter occupants. An exception to this might be a communications center where the noise, if of sufficient intensity and pitch, could interfere with communication operations. The considerations in a dual-purpose shelter will depend on the normal use and noise would be a factor in determining the duct design. Even in this case, however, noise

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*Aspect ratio is defined as the ratio of the long side to the short side of a duct.

created by increasing duct velocities in order to supply greater amounts of air to occupied shelter areas would not be objectionable.

As previously indicated, an air supply system which introduces all of the air at the end of the shelter remote from the exhaust outlet would probably provide the lowest average effective temperature during warm weather when thermal control is by ventilation only. In this case, there would be no distribution duct system. The air would be supplied at one end of the shelter at low velocity and exhaust near the ceiling at the other end. Ideally there would be little mixing of the ventilation air with the shelter air. Actually, there would probably be some mixing at certain locations and stagnation at other points.

In this type of system the air could be supplied through a plenum chamber with large openings and baffles to give even, low-velocity distribution. Alternatively the supply could be through perforated metal duct, or a duct with a longitudinal slot of varying width, installed across one end of the shelter. If perforated duct is used, the holes would be of varying diameters to give even distribution or a method of blocking off some of the holes would be necessary.

The air outlets from the distribution ducts could be standard commercial grilles, possibly of the double deflection type in order to adjust air distribution, or circulate ceiling diffusers. If the static-regain method of duct design is used (see Chapter 12, 1963 ASHRAE Guide and Data Book) the system should be essentially self-balancing and it may not be necessary to provide dampers at the outlets. However, in the actual installation, resistances to flow may not be exactly as calculated due to variations in smoothness of materials, types of joints, and variations in workmanship. Consequently, some balancing may be required after the system is installed and dampers may be desirable. The cost factor will probably determine whether or not they are installed.

Figure 12.1 indicates that the generator room is cooled by exhaust ventilation air from the shelter space and equipment room, plus recirculating unit cooler. If the unit cooler is not provided, the requirements for ventilation and combustion air must be considered very

carefully to determine whether adequate air will be available from the ventilation exhaust. A typical 100-hp auxiliary power system could require as much as 2000 cfm of ventilating air for the power system enclosure. Of this, about 25 percent would be required for combustion and the remainder to carry away the heat rejected directly to the enclosure (41). If the jacket water cooling system uses any components within the enclosure which require cooling air, such as a radiator, the ventilating air requirements would be significantly greater. It might, therefore, be necessary to provide an additional intake and blower to provide air for the power system enclosure.

In any case it would be desirable to consider a remote radiator unit outside of the enclosure to remove the heat rejected to the engine coolant. This would require additional piping and probably an additional circulating pump but this would very likely be less expensive than providing the additional air required to remove this heat from the enclosure. If adequate water is available a direct make-up-water cooling system might be considered.

In a single purpose shelter, the system would be designed and the components selected on the basis of minimum cost for a system which is adequate for austere conditions. In a dual use shelter, on the other hand, the normal use of the facilities will dictate that the system be designed and installed to conform to established codes and standards and in accordance with good engineering practice, with the possible exception of features which are solely for emergency use. However, even in single purpose shelters local building codes should be followed and the pertinent codes and standards should be observed wherever possible.

CHAPTER XIII

SHELTER OPERATION AND MANAGEMENT

This book is concerned with the problems involved with the control of the chemical and thermal environment in shelters. The emphasis is on the criteria and systems which must be considered to create a tolerable level of habitability. Yet it must be remembered that the objective of this effort is to provide a refuge for people in case of nuclear attack, or natural disaster, and that the survival of these people is the purpose of the shelter. It may well be that survival of the occupants will depend to a great extent on the effectiveness of organization and quality of management, as well as level of protection and efficiency of the mechanical systems which are provided.

An extensive consideration of the concepts and techniques of shelter management and operation are obviously beyond the scope of this discussion. Those who wish to pursue the subject in depth can find more information in the Federal Civil Defense Guide and in some of the publications listed in the appendix of this book. There are also courses for shelter managers available from time to time in most areas of the United States.

The intent of the chapter is to suggest some possible ways in which the requirements for organizing, managing and operating a shelter may have an impact on the design of shelter facilities. Certainly the design of a shelter area in a building can help to facilitate the organization of, and effective operation by, the occupants if some of the requirements are considered during the planning stages. Unfortunately there is an almost total lack of definitive information in this area at the present time. Consequently all that can be done here is to suggest some of the possibilities which might be considered.

There is no identical experience in the human past which can provide a true insight into the sociological and psychological conditions which might exist in an occupied shelter following a nuclear attack. It is to be expected that the shelter will be occupied by a heterogeneous group of people who have been uprooted from the normal pattern of their lives and crowded together in the confined space of the shelter under conditions of extreme physical and emotional stress. They may enter as complete strangers to

each other, many of them separated from their families and ignorant as to the fate of their loved ones. Of necessity the shelter will be crowded, possibly even overcrowded, and living conditions will be austere. It would be difficult to devise a more rigorous test of social and psychological adjustment and it will require vigorous, informed and dynamic leadership to prevent conditions from deteriorating to the point where the survival of the occupants would be in jeopardy.

Although it is impossible to simulate all of the conditions which would exist in a shelter under emergency conditions, there have been tests conducted in shelters with human occupants which have yielded some valuable information concerning the emotional response to the shelter environment as well as the physiological response.

The sources of discomfort and complaint, as revealed by questionnaires filled out by the occupants, were about as would be expected. The exact rankings of the discomfort factors varied from test to test but most of them gave high rankings to such things as noise, lack of water, crowding, heat and humidity, food, dirt, and difficulty in sleeping. There were other factors mentioned but those listed were the ones generally receiving the highest rankings. There was a somewhat surprising lack of indications of interpersonal conflicts.

The complaints about lack of water involved water for washing purposes, since, in most of the tests, there was no restriction on drinking water or the allowance was generous enough to cause no hardship. Obviously this complaint is closely associated with the complaint about dirt.

In many of the tests the thermal environment was well within the comfort range, either due to favorable outside air conditions or because conditions were deliberately controlled to provide comfortable effective temperatures. However, when the effective temperatures in the shelter exceeded about 78° FET, heat and humidity were the highest ranked discomfort factors.

Complaints about noise appeared to stem from noise created by the occupants more than from noise generated by mechanical equipment, although the latter was a factor.

Tests conducted with a trained, designated manager in the shelter were more successful than those without a designated manager. In tests where there was no designated manager, and in one where the manager deliberately adopted a passive attitude, it was found that leadership, organization and functioning were poor or less effective as evidenced by such findings as deterioration of standards of cleanliness, higher noise levels and more difficulty due to behavior of individual occupants. The larger the shelter, and the more complex the performance requirements of protective shelters, the more critical were the leadership and technical qualifications of shelter managers and staffs to shelter performance.

Since all of these were supervised and monitored tests there were many factors involving management of a shelter which the designated manager did not have to handle. The occupants were screened to eliminate persons with serious physical or psychological disorders. There was adequate medical care available and persons who were ill or mentally disturbed could be, and in several cases were, removed from the shelter. The mechanical equipment was thoroughly checked and tested and outside technical assistance was available, if needed. Finally, all of the occupants knew that it was only a test and that no real emergency existed. In most cases, they knew exactly how long they would be in the shelter and also knew that they could leave if conditions got too severe. Consequently there were many factors which could not be revealed by these tests which could become matters of life or death in an occupied shelter after a nuclear attack.

The survival capability of any shelter can be increased dramatically by plans made and actions taken prior to shelter occupancy. Establishing and maintaining a community shelter in a state of operational readiness is more than just procuring supplies and equipment and storing these in or near the shelter. Of at least equal importance are the procedures for organizing and operating the shelter which can be developed in the form of a shelter plan. The pre-occupancy management planning should be done by the shelter manager, working in conjunction with local civil defense authorities.

The first step in this planning is to determine what survival capabilities the structure provides and what is required to reach the desired level of survival capability. It will then be necessary to determine the amount and

kinds of supplies and equipment which will be needed. Once the supplies have been procured, it is necessary to move them to the shelter and store them in or near the shelter area. The decision as to where to locate the supplies can be a crucial one since they should be placed so that (a) they may be easily monitored and inventoried, (b) they remain in good condition, (c) they are safe from unauthorized use and (d) they can rapidly be brought into the shelter (if they must be stored outside the shelter area).

Once these first steps have been accomplished, consideration can be given to organizing the shelter. The minimum number of shelter managers and assistants necessary to direct and control shelter operations will range from one person trained in shelter management for every 75 persons to be sheltered (in the case of 50-100 person shelters) to one for every 375 persons (in the case of 5,000-10,000 person shelters.) Specific management requirements will also depend on the shelter configuration, status of supplies, availablity and competence of the shelter leadership, and the shelter environment. In a small shelter, successful completion of tasks may require action only by a manager and a few assistants. In large shelters, it may be necessary to organize a number of teams, each with a specific responsibility.

A complete shelter management operations plan would define:

1. How to distribute the population within the shelter facility.

2. How to assume and maintain command of the shelter, with special guidance prepared for the contingency of an untrained shelter manager.

3. The resources of the shelter with instructions on how to use them.

4. How to organize the shelter into core management staff, task teams and community groups, indicating the specific duties and responsibilities of each position in the organization structure.

5. How to schedule and carry out shelter operations and activities, indicating the activities that are necessary and appropriate at different stages of shelter occupancy.

6. Possible emergencies in shelter, and how to cope with them.

7. Preparation for exit and procedures for handling temporary emergence and full-time exit from shelter.

8. Procedures for communicating with shelter complex headquarters, or the Emergency Operating Center.

It is apparent that the decisions made during this planning will be influenced and, in some cases, determined by the features of design of the shelter facility. However the influence of the requirements for operation and management on the design of the shelter cannot be defined with any degree of precision. The almost limitless variety of shelter sizes and configurations will permit only generalization of the types of design techniques which might be considered. A single-purpose shelter of the degree of sophistication shown in Figure 12.1 will allow features of design which would not be possible in a dual-purpose shelter. Shelters located in existing buildings, of course, allow no application of design. Even in new buildings which are being slanted to include shelter, limitations in budget and over-riding requirements for normal function severely limit what can be done in the way of shelter design.

The design objectives for the mechanical system, as established by the requirements for shelter operation are closely interrelated with the design of the structure and layout of the shelter areas. In many cases it will be impossible to consider them independently and, consequently, the mechanical engineer must work closely with the architect. It would be beneficial if both had the consultation of someone trained in shelter planning and management. The person who will be the shelter manager would be the best choice but it would be very unusual for the manager to be designated during the design stages. An instructor of shelter management courses might be the next most logical choice.

The design considerations can be discussed for some of the possible shelter functions. There is no intent that these headings comprise a complete list of functions since some essential activities may have little or no impact on the design.

MANAGEMENT ACTIVITIES

There should be an area set aside for the use of the manager and his staff. Preferably it should be partitioned off from the rest of the shelter so that the staff can perform their duties without interference from the rest of the shelter occupants. The nature of this area will depend on the size and layout of the shelter. It may be a separate room or it might be as simple as a corner partitioned off with stacks of supply cases or a hanging blanket. In buildings with shelter areas on several floors or in different wings it might be desirable to have a management center in each location.

In buildings which might be equipped with an intercommunication system, the management area should be located to include the central control of the system. In any case, the area should be close to any communications facilities for the shelter.

RADIOLOGICAL PROTECTION

The protection against fallout radiation is basically a function of the building design but there are some implications for the mechanical engineer also. The most obvious requirement is that ventilation openings, ducts, etc. do not disturb the shielding integrity. The location of windows, doors and other openings should be planned not only to provide the necessary radiation barriers but also to permit circulation of air in the shelter, to admit outside air or to exhaust air from the shelter.

The requirements for shielding are often not compatible with the movement of air. Windows may be blocked or baffled to increase radiation protection and thereby eliminate air. Baffle walls in front of doorways may inhibit the flow of air. In these cases it may be necessary to provide auxiliary air moving devices such as punkah pumps or portable fans to augment the natural air flow.

A shelter planner may wish to consider areas with a lower protection factor for possible auxiliary uses such as storage of supplies or a storage area for used waste containers. In this case, it may be necessary to provide lights and at least minimal ventilation.

AUXILIARY POWER

It has already been discussed that an auxiliary power system would be very desirable to provide power for lights, ventilation blowers or air conditioning, pumps, communications equipment and possibly even heating and refrigeration of food. The design requirements have been covered in Chapter VII.

From the standpoint of operation of the shelter, the design objective would be to facilitate the operation and maintenance of the system. The power enclosure should be separated from the shelter in order to prevent heat and fumes generated from entering the occupied space and to reduce noise in the shelter. It should be easily accessible from the shelter and provide a reasonable degree of radiation shielding for the protection of maintenance personnel. The design must provide for adequate air for combustion and cooling of the equipment as well as for ventilation of the space.

The necessary operating and repair instructions, together with spare parts and tools should be stored with the equipment and protected from deterioration and pilferage. A locker or tool box which can be locked and cannot be removed should be provided to store these items.

To facilitate operation and maintenance, it would be helpful if color coding were used on piping and conduit. Fuses and circuit breakers should be clearly marked to show which circuits they service. Switches and other controls should be labeled as to their function.

When operating on auxiliary power, it may be necessary to use sequential starting of electric motors or to shut down other equipment when starting a large motor, in order to avoid overloading the power supply. In this case, appropriate instructions and precautions should be posted next to the controls.

Transfer switches to convert from normal to emergency power would, of course, be necessary and should be provided with locking devices so that they can be locked off when on normal power. Any services operating on normal power but which would not be used on auxiliary power should have lock-out devices provided on the controls or be interlocked with the transfer switches.

Operating and maintenance manuals for all equipment should be provided. An extra set of manuals might be included with shelter managers supplies in case the ones normally used are misplaced or lost. The necessary spare parts and tools should be provided also for maintenance and repair.

In shelter design, the possibility of having to use a manually powered system such as the Ventilation Kit should be considered. An exhaust opening should be provided so that the bicycle driven fan can be set up without excessive runs of plastic duct and openings provided at logical points to give effective distribution of fresh air. A layout of the best air flow paths might be provided, to be included with the information to be supplied to the shelter manager, with possible methods of creating walls or barriers with supply cartons, blankets or other materials to channel the flow.

CONTROL OF THERMAL ENVIRONMENT

There are several management functions which will affect the thermal environment over which the designer has little or no control. These would include physical activity of the occupants, the method in which the equipment is utilized, the use of open flames for cooking, the humidity and odors produced by uncovered containers of water, waste disposal receptacles or garbage and control of smoking in the shelter.

It is necessary that the shelter management staff know what equipment is available and how to use it to the best advantage. If conversion of a normal air supply system to emergency operation is necessary, complete and detailed instructions should be provided as well as instructions for controlling or adjusting airflow in various parts of the shelter, if this is possible with the available system.

The shelter facility should be designed to take maximum advantage of natural ventilation to supplement or replace mechanical ventilation. Instructions and diagrams for the use of natural ventilation should be provided since it is probable that the management staff will not be knowledgeable in this area.

It would be desirable to provide simple instruments

for monitoring the thermal environment such as a sling psychrometer, with instructions, and a chart or table of effective temperatures as a function of dry bulb and wet bulb temperatures. Instruments to monitor oxygen and carbon dioxide content of the air would also be useful.

WATER AND FOOD SUPPLY

The amount and type of food supplied to the shelter can have a significant effect on the control of the thermal environment. If only the survival supplies provided in the NFSS stocking program are available, there will be very little impact on the design of the mechanical systems. If this diet is supplemented or replaced from other sources there can be effects which must be taken into account.

If the food provided for the shelter requires cooking, the additional heat and humidity must be considered in the design of the ventilation system. The cooking area should be close to the ventilation exhaust or separate exhaust provisions be made to remove this additional heat and moisture. If, however, the cooked foods are carried into the main shelter area, either for distribution or by the occupants after distribution, an additional load will be imposed on the ventilation system. This would also increase the possibility of spillage or deposition of garbage throughout the shelter.

Thus it would be desirable from the standpoint of both ventilation and housekeeping, to have an eating area set aside. This should probably be adjacent to the cooking area to facilitate food distribution. Ventilation air should flow from the eating area to the cooking area and then be exhausted.

The type of food provided can effect the metabolism of the occupants. With a more or less normal diet, a somewhat higher metabolic rate can be expected than would occur with the austere diet provided in shelter supplies. A diet high in protein, or salty foods, would increase the water consumption.

If normal food supplies are to be provided, it may be necessary to include refrigerated storage in the shelter. This, of course, creates an additional requirement for power. In any case, it would be desirable to provide, if possible, a cool, dry space for food storage. This

would help to inhibit deterioration of the food, rusting of metal containers, and the growth of mold on fiberboard or paperboard packages. This area should be close to the food preparation and distribution areas and provisions should be made to protect the stored foods from pilferage.

Water distribution in the shelter may be from a central point or by transporting containers through the shelter to carry water to the occupants, or a combination of these methods. Transporting large containers through a crowded shelter could be difficult and the possibility of spillage would be increased but this would require the least physical activity since only a few people would have to move about.

Distribution from a central point would facilitate supervision and equitable distribution of the water and minimize waste. However, each person would have to move to the distribution point which could create traffic problems and would raise the general level of activity, and metabolic rate of the occupants. Under conditions of high effective temperature, when water demand would be greatest, this would impose an additional load on the thermal control system.

If the water supply is entirely from water drums, it would probably be best to set up several fixed points of distribution. These could be determined in the pre-occupancy planning, depending on the size and configuration of the shelter. If, however, water is supplied from a storage tank, or from trapped water, the designer can facilitate the distribution by providing water outlets at several locations in the shelter area. These should be spaced so as to minimize the amount of movement required for the occupants to obtain water and at the same time permit the management staff to exercise suprevision of the distribution. These distribution points can, of course, be set up for the distribution of food as well as water.

LIGHTING

No special lighting levels above those designed for the normal function of the space are required for fallout shelters. At least minimum lighting will, however, be essential for shelter operation and some provision for this could be considered in the shelter design and operational plan.

General lighting should provide a sufficient level of illumination for movement about the shelter, performance of general shelter tasks and reading. A higher level of illumination would be necessary for special functions such as medical treatment, reading instruments and equipment maintenance. Emergency lighting probably battery operated, should be available in case of failure of the main system.

Recommended lighting levels would range from 2-5 foot candles in sleeping areas up to about 25 foot candles for medical treatment and equipment maintenance. General lighting should probably be about 10 foot candles although somewhat less, perhaps 5 foot candles, would be acceptable for corridors or other areas where all that is required is illumination for personnel movement. At least 20 foot candles should be provided for reading and administrative work.

If utility power remains available it is probable that the existing lights in the facility will be adequate although spot lighting may be required for some areas requiring high intensity illumination. Portable spotlights, trouble lights or lamps could be used for this purpose.

If it is necessary to use an auxiliary power system, all or only part of the normal lights may be connected, depending on the power available and the lighting needs. If all of the lights can be used the situation is not particularly different from the normal conditions. When available power limits the number of lights which can be connected it becomes necessary to consider the shelter application as a separate problem from the normal lighting system.

A choice must be made between incandescent and fluorescent fixtures. There are advantages and disadvantages to each type. The incandescent lights are cheaper to install and less sensitive to voltage fluctutations. They can also be dimmed by rheostat control to reduce illumination levels or to conserve power. Fluorescent lights will require less power for a given light level and will generate less heat than incandescent lamps. However, the wiring and equipment is more complex and more expensive. Fluorescent lights are not subject to dimming be rheostats.

In general, fluorescent lights would be the better choice for shelter on the basis of lesser power consumption and reduced heat generation. They also produce light which is more free from glare and shadows. It is also quite possible that the normal lighting in public buildings will be of the fluorescent type. In apartments or other residential-type structures it is more likely to find incandescent fixtures. Thus, in dual-purpose shelters, the choice may be determined by the normal use installation. In buildings being slanted to include shelter, however, the shelter requirement may influence the choice of normal use fixtures.

It should not be overlooked that the shelter operations may require lights in spaces where they are not normally installed or a higher level of illumination than is needed for normal use. This may include storage or service areas normally provided with minimal lighting but which may be principal shelter areas under emergency conditions. Corridor lighting is quite often provided at a relatively low level but the corridors in a building may be the best protected space for shelter.

The control of illumination in a shelter may require special planning of the circuits and switches. If only part of the lights can be operated by auxiliary power these should be on a separate circuit connnected to the power source by a transfer switch. This switch should also disconnect the lights which are not to be used. If this separate circuit is not provided, power consumption can be reduced by loosening bulbs or tubes in their sockets but there is still the possibility that the shelter occupants will tighten the bulbs to get more light and overload the power system. The bulbs could, of course, be removed completely to prevent this.

It would also be desirable to provide for variation in illumination levels during shelter operation. During daylight hours there may be enough light infiltrating to the shelter area to permit turning off part of the lights. It would be desirable to be able to reduce illumination in sleeping areas which may be used only part of the time for sleeping and for other purposes during the rest of the time. In some shelters it may be necessary for occupants to sleep in shifts and the sleeping area would remain at a low level of light all the time.

It would be possible to control illumination by loosening the bulbs or tubes as required but it would be better to provide separate circuits with separate switches to activate the required portions of the lighting system.

When only part of the normal system is to be used for shelter lighting there is probably little need to stock spare light bulbs or tubes. These can be removed from unused fixtures to replace burned out lights, assuming they are the same size and type. If the entire normal system is to be used, some spare bulbs should be stocked although a few inoperative lights may not be of critical importance. In a single-purpose shelter, it could be assumed that all of the installed lights are needed and, therefore, spare bulbs or tubes should be stocked.

It has already been mentioned that higher intensity light can be provided at spots where needed by the use of portable spot lights, trouble lights or lamps. It will, however, be necessary to provide appropriate electrical outlets and these should be connected to the auxiliary power source, if one is to be used. Extension cords may also be required to locate the light where it is needed.

Emergency back-up lighting is needed in case of power failure. Many places of public gathering, such as theaters and stores, are already equipped with battery-powered emergency lights. If these are installed, they may be deficient for shelter use. However, it would probably be better to supplement them with portable flashlights and lanterns powered by dry-cell batteries. In shelter areas without installed emergency lighting, the flashlights and lanterns would be essential.

Other types of emergency lights, such as gasoline or kerosene lanterns or propane gas lights, might be considered but these are combustion devices which add heat and humidity to the atmosphere. They are also a fire hazard both in operation and from the fuel storage. During operation in a crowded shelter, they could cause burn injuries to the occupants.

Dry-cell batteries for use in the flashlights and lanterns have a relatively short shelf-life although the newer mercury cells and nickel-cadmium batteries will last longer on the shelf or in operation than the standard batteries.

MEDICAL FUNCTIONS

The extent of the medical function in a shelter will depend on the personnel, facilities and supplies available. The basic objectives of medical treatment in the shelter are to treat injuries and the symptoms of illness, to reduce pain, and to prevent the spread of communicable disease.

With the lack of professional medical personnel and limited supply of medicines and drugs, in most shelters it will not be possible to cure illnesses or serious injuries. It will be possible only to provide first aid treatment for injuries and simple medication for the symptoms of disease. Beyond this it would be possible to do little more than reduce pain and try to keep the patient as comfortable as possible. Of major importance, however, would be the prevention of the spread of contagious diseases in the shelter.

An area should be set aside in the shelter for medical treatment. It should be closed off from the rest of the shelter, preferably in a separate room, but at least by an improvised partition. This will give some privacy for diagnosis and treatment. An adjoining area, isolated from the rest of the shelter, should be set up for patients with contagious illnesses. A sanitation area should be set up near the medical area to allow for the disposal of medical wastes and because the sick and injured are likely to have more extensive need of the sanitary facilities. Obviously this area should not be close to the food preparation and distribution areas.

The standards of cleanliness and disinfection in the medical area should be maintained as high as possible. This is another reason for separating it from the rest of the shelter since experience in shelter tests indicates that the cleanliness in the shelter will be much less than the normal conditions to which people are accustomed. Noise levels in the shelter will also be high and it would be desirable to isolate the sick and injured from this noise as much as possible.

It has already been mentioned that a higher level of illumination would be needed in the medical treatment area. However, a lower level may be best in the patient care area so that patients can more easily rest or sleep.

in order to keep the sick patients as comfortable as possible it would be desirable to provide more ventilation in this area or locate it in the most favorable area from the standpoint of thermal control. It would be necessary that air from this area not be circulated to the rest of the shelter in order to help prevent the spread of air-borne, disease-causing organisms.

SANITATION

Sanitation requirements and systems were discussed in Chapter IX. There are, however, some additional aspects to be considered from the operational viewpoint.

The toilet facilities should be located away from the living quarters, if at all possible. Under any circumstances arrangements should be made to shield the toilet area from public view and provide as much privacy as possible. Separate facilities for men and women should be set up if conditions and shelter configuration permit.

If the sanitation drums are used they can be set up in any location which seems to be appropriate. However, they are difficult to move when filled and consequently the sanitation area would best be located near an exit to the area where the filled drums will be stored.

In order to reduce odors and possible spread of contamination air from the sanitation area should not be circulated to the shelter living spaces. Therefore, this area should be near the ventilation exhaust. It may be possible to exhaust air through the same exit. which is used to dispose of the filled drums.

The toilets should, of course, be as far away as possible from the food and water storage and food handling areas.

FIRE PROTECTION

In any area of human habitation, fire hazards exist and a fire in the shelter is a possibility which must be considered. Fires may result from smoking, electrical equipment, cooking devices or other open flames, or from spontaneous combustion. If a fire should occur, the occupants of the shelter cannot leave to escape it and consequently, provision must be made to prevent fires from starting and to extinguish any which might start.

The prevention of fire is partly a function of the shelter design and partly a matter of management and good housekeeping practices. Precautionary measures which can be taken in the design and construction of the shelter might include the use of non-flammable and fire-retardant paints and finishes, avoiding the use of combustible wall boards, acoustical tile,etc., using fabrics treated to resist fire, installation of electrical equipment in accordance with good practice and provision of explosion-proof motors and controls in areas where flammable vapors or dust might occur, location of fuel storage tanks so that vapors will not enter the shelter and similar techniques. Most of these are well established practices and are provided for in most fire codes.

The management procedures and housekeeping practices are also well known and can be found in standard reference works on fire protection. Their implementation is principally a matter of training of the management staff and enforcement of the practices in the shelter.

If a fire should start in the shelter, early detection will be imperative if the fire is to be controlled and extinguished. Fire detection instruments, such as heat sensors, smoke detectors or gas analyzers, may be available in some buildings which contain shelter areas. However, in most cases, they will not be available and their high cost probably could not be justified if they were to be installed for shelter use alone. Therefore, the principal method of detection would be by personal observation by the occupants.

It is difficult to conceive of a fire remaining undetected for very long in a crowded shelter. It is possible, however, that a fire could start in a storage area or equipment room which would be unoccupied. It might also start in a part of the building not being used for shelter. Therefore, one of the responsibilities of the shelter manager should be to establish a 24-hour fire watch in the shelter.

If a fire should occur it will be essential that facilities be at hand to effectively extinguish it. Water is the most common extinguishing agent but it probably should not be used for fire fighting because it may be in short supply and is essential for survival of the shelter occupants. In fact, one important source of

trapped water in a building may be the fire sprinkler system or other fire control system. It would be possible to use waste water or non-potable water for fire-fighting, if it is available. If there is no other method available, the potable water supply would have to be used since there would be no point in saving water if the shelter burned.

Standard types of hand fire extinguishers may be provided; in fact, they may be installed for normal operation of the buildings. There are limitations in their effectiveness, however, and precautions in their use which must be observed. The common soda-acid type uses water as the extinguishing agent and would be effective against paper, wood, or trash fires. It is useless on burning oil or gasoline and could be fatal if one tried to use it on an electrical fire, unless the electric current were turned off first, since the water-acid stream is electrically conductive.

Chemical foam extinguishers are effective against burning hydrocarbons and also against wood and paper fires. They should not be used on electrical fires for the same reason that the soda-acid type should not be used. The foam residue would be very difficult to clean up without plenty of water and cleaning agents.

Vaporizing liquid extinguishers, such as carbon tetrchloride, are effective against electrical fires and moderately effective against other types but they should never be used in a closed shelter. Carbon tetrachloride vapors are toxic and in contact with the heat of a fire will generate other toxic gases such as chlorine and phosgene.

Carbon dioxide and dry chemical extinguishers are effective against almost all types of fires and are safe to use in well ventilated spaces. In a small room or underventilated space, they could be dangerous because of the large amounts of carbon dioxide released. In a confined space this could cause suffocation. The increased carbon dioxide content in the shelter air might cause temporary discomfort but if there is adequate ventilation, it should not be dangerous.

Sand or earth may be stored in buckets for use on fires. They would be effective in smothering a fire if sufficient quantities are available and if the fire is on a

horizontal surface. They would be ineffective on an irregular or vertical surface. Sand, of course, could cause serious damage if used on machinery.

Blankets, rugs, coats or similar heavy fabrics can be used to smother or beat our a small fire. especially if they are dampened. A dampened broom may also be used. These could be quite effective if the fire is detected early.

It is apparent that there is no one fire extinguisher or extinguishing agent which would be effective on all types of fires and safe for use under all conditions. The soda-acid type would be relatively safe to use in a shelter and might be provided in areas where only paper or trash fires are likely to occur. In areas where electrical or flammable liquid fires might occur, the dry chemical extinguisher might be the best choice in spite of the carbon dioxide hazard. Dampened blankets should probably be tried first on small fires before any other extinguishers are used.

COMMUNICATIONS

It will be necessary to provide for communications both within the shelter and outside the shelter. In a large shelter, an intercommunication system would be very desirable if one is installed in the building and power is available. This might be either of the loud speaker or telephone type. Lacking this, battery-operated or sound-powered telephones, a portable loud speaker system, or walkie-talkies could be provided. A battery powered megaphone would also be a possibility. In some cases, however, it may be necessary to rely on messengers to communicate with various parts of a large shelter.

With the wide use of portable, transistor radios in modern society, it is very probable that many shelterees would bring radios with them into the shelter. These could be used to receive communications from the Emergency Broadcast System, (EBS). This system will keep the public informed of radiation levels, post-attack conditions, potential danger areas, directions from emergency control centers and other essential information.

Two-way communications would be desirable with civil defense control centers for reporting information on radiation levels or emergency conditions and receiving information and advice. It would also be helpful to be able to exchange lists of occupants with other shelters, through the control center, to help people locate other members of their families who might be separated from them. This two-way communication might be by radio, by wire, or by protected telephone lines.

If communication is to be by radio, it will be necessary to provide an outside antenna and appropriate lead-in wires. Indoor or built-in antenna systems could be ineffective because of the shielding effect of the shelter structure.

HOUSEKEEPING

One of the problems in the shelter will be the control of dirt and debris. The shelter facility should, therefore, be designed to be as easy to keep clean as possible. Concrete floors should be sealed and painted to prevent dusting and facilitate sweeping. Furniture and equipment should be painted or the surface sealed for the same reason.

Essential cleaning equipment such as brooms and mops should be provided as should rags, paper towels, and other supplies. Consideration might be given to providing a commercial sweeping compound to aid in holding down dust during sweeping operations. The types of equipment and supplies, the amount required, and the storage locations in the shelter will be determined by the size and layout of the facility.

Industrial organizations for many years have used paint and color to provide a more cheerful work environment and to improve plant housekeeping. The same techniques could be applied to a shelter to make the shelter appear more livable and encourage the occupants to keep it clean. The technique of painting a white circle at the corners of the floor has been found to be effective in preventing the accumulation of dirt since the dirt becomes highly visible and is therefore cleaned up.

The red, yellow and orange colors should not be used on walls, ceilings, or floors since these colors tend to make people feel hot regardless of the temperature.

Blue, green and colors in between should be used instead since these are "cool" colors. Walls which are lighter color at the top than at the bottom and light colored ceilings give the illusion of more space. Light colored walls appear to recede or be farther away than do dark colors. Color accents in the furniture or equipment help to make the space more "livable". The use of "battleship" grey, olive drab, or plain white should probably be avoided since these are associated in the minds of most people with institutional living or confinement.

Since most surfaces and equipment in a shelter should be painted for preservation and necessary maintenance there is very little additional cost involved in painting for the psychological effect. Commercial and industrial designers use these techniques all the time and there appears to be no reason why they should not be applied to shelter design.

In considering the various planning and design techniques which might be applied to a shelter, it is evident that all of them cannot be used in any one facility. Indeed, some of them are mutually exclusive.

It was mentioned that medical treatment areas should be located near the ventilation exhaust and should have the most favorable effective temperature. But with a series flow of ventilation air, the area next to the exhaust outlet would have the highest effective temperature. Although series flow will normally provide the best conditions for the greatest portion of the shelter, a compromise may be necessary in the case of medical areas.

In discussing food cooking areas and toilet areas, as well as medical areas, it was pointed out that ventilation air should be exhausted from them without circulating to the shelter. Yet it was also stated that toilet areas should be located as far as possible from food preparation. This obviously can create a design conflict and the designer or planner may be required to make a choice. Since air is exhausted from the toilet areas and medical treatment areas to prevent the spread of disease as well as odors, it may be better to take care of this requirement first. This may require elimination of cooking, if the heat and moisture cannot be tolerated in the shelter, or limiting cooking to such times as the shelter conditions will allow it.

Similar conflict and the need for compromise can and will occur in other areas of shelter planning and design.

The success or failure of the shelter, and the survival of the occupants, will depend to a large extent on the ability, training, leadership, wisdom and dedication of the shelter manager and his staff. They will carry an awesome responsibility and deserve to be provided with a shelter structure and systems which are as safe, reliable and habitable as can be devised by the ability and ingenuity of the architects and engineers who design them.

APPENDIX A

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